EMPOWERMENT

SENIOR DESIGN II: EE-41440

FINAL DOCUMENTATION

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TABLE OF CONTENTS

1. Introduction 4
1.1 Problem and Solution 4
1.2 System Requirements 4
1.2.1 Overall System 4
1.2.2 Generation Subsystem Requirements 5
1.2.3 Monitoring Subsystem Requirements 6
1.2.4 Storage Subsystem Requirements 6
1.2.5 Load Subsystem Requirements 7
1.2.6 Future Enhancement Requirements 7
1.3 High Level Design 7
1.4 Expectations 8
2 Project Description 9
2.1 System Theory of Operation 9
2.2 System Block Diagram 9
2.3 Generation Description 10
2.3.1 Wind Power Generation 10
2.3.2 Solar Power Generation 12
2.3.3 Power Generation Testing 13
2.4 Monitoring and Control 14
2.4.1 Microcontroller 14
2.4.2 Hardware: Sensors 16
2.4.3 Hardware: LCD Display 18
2.4.4 Hardware: Data Storage 19
2.4.5 Software: 20
2.5 Storage 24
2.5.1 Battery 24
2.5.2 Relays 24
2.5.3 Switches 26
2.6 Load 26
2.7 System Housing and Construction 27
3 System Integration 29
3.1 Testing Methods 29
3.2 Fulfilling Requirements 30
4 User's Manual 31
4.1 System Installation and Set-up 31
4.1.1 Additional Hardware Selection 31
4.1.2 Connections 31
4.2 Everyday Use 32
4.3 Troubleshooting 33
5 Conclusions 34
5.1 Results 34
5.2 Future 34

Appendix A: Schematics and Board Layouts
A1: Main Board Schematic 36
A2: Main Board Layout 37
A3: Sensor Board Schematic 38
A4: Sensor Board Layout 39
A5: Hall Effect Board Schematic 40
A6: Hall Effect Board Layout 41
Appendix B: Software
B1: A2D.h 42
B2: A2D.c 42
B3: Relay.h 46
B4: Relay.c 46
B5: RotSens.h 47
B6: RotSens.c 48
B7: RTClib.h 49
B8: RTClib.c 50
B9: spiLCD.h 54
B10: spiLCD.c 55
B11: main.c 61
Appendix C: Bill of Materials 68

1 INTRODUCTION

1.1 Problem and Solution

People all over the world make do without electricity. Living without electricity in many cases means living without hope of development. Lack of electricity keeps people especially susceptible to disease, eliminates the possibility of studying or any sort of income generation occurring after sunset, and keeps rural populations out of touch with the rest of the world. However, for many developing countries, the bureaucratic and technical difficulties associated with installing, much less maintaining, effective infrastructure make those improvements out of the question. The solution lies in providing low cost, robust, off-the-grid energy generation systems. We are hoping to design a system that uses two renewable energy sources, solar and wind, to provide power for a household. We plan for the system to power a useful appliance reliably, to store excess energy, and to require minimal user maintenance.

For many people in the developing world, the only available energy sources are dirty, unsustainable, and often expensive. Some of these sources include hard-to-find fossil fuels that emit green house gasses. Other carbon-based fuels include animal waste or firewood, both of which are time consuming to gather and give off unhealthy smoke and particulates when burned. In addition, using wood as fuel leads to deforestation, draughts, and further impoverishment. Living without electricity in many cases means living without hope of development. Lack of electricity keeps people especially susceptible to disease, eliminates the possibility of studying or any sort of income generation occurring after sunset, and keeps rural populations out of touch with the rest of the world. However, for many developing countries, the bureaucratic and technical difficulties associated with installing, much less maintaining, effective infrastructure make those improvements out of the question.

Off-grid small-scale power generation systems that rely on renewable fuels are a clear answer. In addition, we would like to make use of readily available materials that can be found or manufactured easily in many places around the world. Our design harnesses energy from both the sun and wind. We plan to use inexpensive crystalline silicon photovoltaic cells and a wind turbine connected to an old car alternator to first produce the electricity. Then we will use circuitry to add the power together and charge a 12V battery. The battery will then be used to power appliances.

1.2 System Requirements

1.2.1 Overall System

Our system has four main subsystems: energy generation, monitoring, storage, and load.

Our generating subsystem consists of a small wind turbine connected to a car alternator, and a set of monocrystalline silicon photovoltaic cells. The combined efforts of these two power sources should be able to provide between 20-25 amps at 12 volts.

The generation is dependent on mechanical design decisions and the environment; by choosing the appropriate pulley system and by optimizing the direction of the solar panels and the turbine, the generated power at full production levels should be around 240W-300W.

The monitoring subsystem consists of a variety of sensors feeding into a microcontroller, which will monitor and control the behavior of the system according to various threshold voltages. The microcontroller will read in the voltages from the generation system and the battery, the current from the solar panels, the alternator, and the battery, and the rpm of the turbine. The up-to-date results of these sensors will be displayed to the user on an LCD display. Also included in this subsystem is an SD chip, which will store the data being gathered by the sensors. Having this information, especially in the early stages of the project, will enable us to analyze and optimize the system.

The storage subsystem consists of a 12V lead acid battery, relays, and a passive deep discharge protection circuit. The monitoring subsystem will keep the microcontroller up-to-date on the voltage of the battery. If the battery voltage reaches above 14V, then the microcontroller will signal the relay to disconnect the battery from the generating subsystem in order to protect the battery from overcharging. If the battery falls below 10V, the microcontroller will signal another relay to disconnect the battery from the load. As an extra safeguard, the inverter automatically disconnects when the battery falls below 9.5V. These protection measures should extend the battery's lifetime and the usability of the system. The relay on the generation side plays an additional role. The turbine will not be able to start moving if it starts off loaded. The microcontroller needs to open the relay so that the turbine is disconnected from the battery until the rotor gains speed. Then the connection can be made and the alternator can begin generating energy.

On the load side we will have dual output. First we will have a 12 V DC ideal for appliances designed for cars, RVs, or high efficiency LEDs. We will also have an inverter that produces 110 VAC ideal for most standard appliances.

1.2.2 Generation Subsystem Requirements

Solar: The solar panels should output a little above 12V for safe charging. In any scenario, the power output of the solar panels, due to budget and space restrictions, will be much lower than the output of the alternator when it is running. However, to charge a 12V battery on solar power alone within one day, approximately 40W is necessary. This estimate is based on solar systems already used in the field and advice from Professor Freeland. Therefore this subsystem requires enough solar cells to produce around 40W.

Wind: Charging a battery safely requires a fairly stable voltage. Any alternator selected needs to have a regulated 12V output, or the voltage from the alternator needs to be

rectified in some way before reaching the battery.

We are anticipating wind speeds of around 15-20mph, which corresponds to 15-20A. Wind speeds increase with vertical height, so the turbine can take better advantage of wind if it is elevated significantly.

1.2.3 Monitoring Subsystem Requirements
Sensors: The voltages being monitored will hover around 12V, so the voltage sensors need to be able to measure with some accuracy at that level. The current coming from the solar panels will be less than 1.15A, the current from the alternator will hopefully be around 30A, and the current from the battery will most likely be somewhere in between. The current sensors need to be able to measure with some accuracy at these varying levels. The average speed of our wind turbine, predicted by the plans, will be around 600 rpm. We need a rotation sensor that can measure with some accuracy at this speed. We also need some way to convert the signals from the sensor into an rpm value using software.

Microcontroller: We have decided to run our board at 5V, so the microcontroller needs to operate at that voltage. Many of our components will require SPI, so the microcontroller must be able to handle that.

LCD Display and User Interface: This display is the main way the user will get to see what kind of power the system is producing and what the current charge of the battery is, especially if the user does not have a computer or any other way to read the SD card. The interface and print-out to the screen should be intuitive and easy to interpret.

Data Storage: We want some way to record the outputs from the sensors over an extended period of time. This feature will be particularly useful for optimizing the system and determining what conditions produce the most power. In order for users to make sense of the data recorded, the log should ideally also include some reference to the date and time of each reading. This might require an additional Real Time Chip. This also might require the user to input the starting date and time into the microcontroller at the beginning of recording. This would require a user interface with push buttons. The system needs to be large enough to store at least 30 days of data at a time.

1.2.4 Storage Subsystem Requirements
Battery: The system requires a 12V battery. The system is intended for rough conditions and continuous use, so a robust battery that is suited for float charging is optimal. Ideally, the battery should also be able to withstand deep discharge without complete failure, as the unpredictable nature of solar and wind energies might strand the system without any fuel for unknown lengths of time.

Relays: The relays are responsible for either conducting or disconnecting the current

between the generators, battery, and load. Therefore they must be robust enough to handle the high amounts of current. They will be receiving a signal from the microcontroller to switch, so they must respond to a signal of less than 5V. This system is trying to conserve energy at every opportunity, so these relays should also ideally not waste much, if any, power while engaged.

1.2.5 Load Subsystem Requirements
Inverter: Most easy to find appliances that a family would want to power run off of AC power. The battery stores power in DC. Therefore, the system requires an inverter that can take power from a 12V DC battery and create AC power appropriate for the appliances that the user wants to power.

DC Output: The user might also have DC powered appliances, and the system should be able to handle these too. The DC output should provide 12V of DC in a way that is easy for the user to access and use.

1.2.6 Future Enhancement Requirements
An increase in power production could be achieved by optimizing the wind turbine design. The mechanics of the turbine could easily be altered without affecting the electronics of the system as long as the design uses an alternator with an internal regulator that outputs 12V DC. More solar panels could also be added easily, provided they are also around 12V and added in parallel.

The SD storage system and user interface have great opportunities to be enhanced in the future. Our goals for this project are simply to have the real-time values of the sensor being displayed on the LCD. In the future, the system could display more calculated values and the user could perhaps search through past records on the LCD screen. The possibilities for this expansion are limited by the processing power of the microcontroller and the available space in the data storage system.

More batteries could be added in parallel and charged simultaneously to increase power.

The current system will most likely only be able to generate enough power for one appliance at a time. In the future, as the other energy generation and storage enhancements are implemented, the system might be able to run multiple loads at once. This could require additional outputs for the inverter.

1.3 High Level Design
Power will be generated by two sources, solar and wind. A monocrystalline silicon photovoltaic cell will produce DC power. A wind turbine will drive a car alternator with a built-in voltage regulator and rectifier to also produce DC power. The two energy sources will be connected in parallel, and the combined power will begin to charge the battery.

Current, voltage, and rotation sensors monitor the power generation system to calculate the amount of power being generated at all times. The voltage and current of the battery is also measured at all times. The results of these sensors is received by the microcontroller and then stored in a data storage system. We have chosen an SD Card and are using an SPI interface to communicate with it. The results of these sensors will also be displayed to the user on an LCD screen, also using an SPI interface.

To protect the battery from over- and undercharging, the system has a few safeguards. In the first case, the microcontroller will monitor the battery voltage level. In the case of over-charging, the microcontroller will open a relay connecting the generating systems to the battery. In the case of undercharging, the microcontroller will open a relay connecting the battery to the load. The inverter we have selected also automatically disconnects when it detects a battery charge lower than 9.5V. In the case that the user wants to override the microcontroller or the microcontroller fails, the system will also include manual switches to control the connections between the battery and the rest of the system.

Power from the battery will enter an inverter so that users may power their traditional AC appliances. A DC power option will also be available by simply connecting the load to the battery terminals, which will be easily accessed.

The energy generation components will be most likely operated outdoors, some distance from the appliances needing to be powered. Cables carrying the power and the rotational sensor signal will need to be run some distance before entering the main system box. The main system box will house the main board, the monitoring system, the relays, and the current sensor boards. The generated power is fed through the box, monitored, controlled, and then delivered to the battery. The battery is connected underneath the box. Then power from the battery is fed back into the box, and then out to the inverter, housed on top of the main box.

1.4 Expectations

The idea for this project started out being very amorphous. The general goal of producing renewable energy for remote locations existed, but the path of how to get there was up for debate for a good part of the first semester. The project does meet our initial requirements; for example, it does create power and charge a battery. However, we were not able to implement some of the more complicated software features, like SD card data storage, in time. Also, we were not able to install a more interactive user interface, which is a feature we discussed.

Our wind turbine's performance was also unexpected. We always intended to build a smaller version of the wind turbine we would recommend for permanent installation of our system. Our final prototype stood only four feet off the ground, but the blades and nacelle were designed to be fully functional at around six meters off the ground. We

were hoping that we would be able to witness the turbine operate, even if it only produced a nominal amount of current. Unfortunately, the threshold wind speed for the turbine blades is 8 mph, and with the large resistance of the alternator, it takes speeds even higher to produce energy. It is very difficult to find those kinds of wind speeds so close to the ground. We did experience some very high wind speeds towards the end of the demo, but it was not consistent.

2 PROJECT DESCRIPTION

2.1 System Theory of Operation

The system receives electric power from two renewable sources. In our demonstration, we are using a wind turbine and two 20W solar panels to produce electricity. These two sources enter a central system box. The main microcontroller board, three current sensor boards, three relays, and three switches are housed inside the system box. Inside the system box, the current and voltage of the two energy sources is monitored and stored. Power is provided to the box by the battery. From this power connection, the microcontroller monitors and stores the charge level of the battery. If the battery charge level is above 14V, or in danger of overcharging, a relay to each source disconnects the battery from the power sources. If the battery charge level is below 10V, a third relay disconnects the battery from the load. If the battery charge level is above 10V, the battery remains connected to an inverter housed underneath the system box. The inverter produces AC power convenient for powering everyday appliances. The battery terminals remain easily accessible for DC appliances. An LCD communicates to the user the present power generation levels, wind speed, the battery charge level, and the amount of power being consumed in English and Spanish.

2.2 System Block Diagram

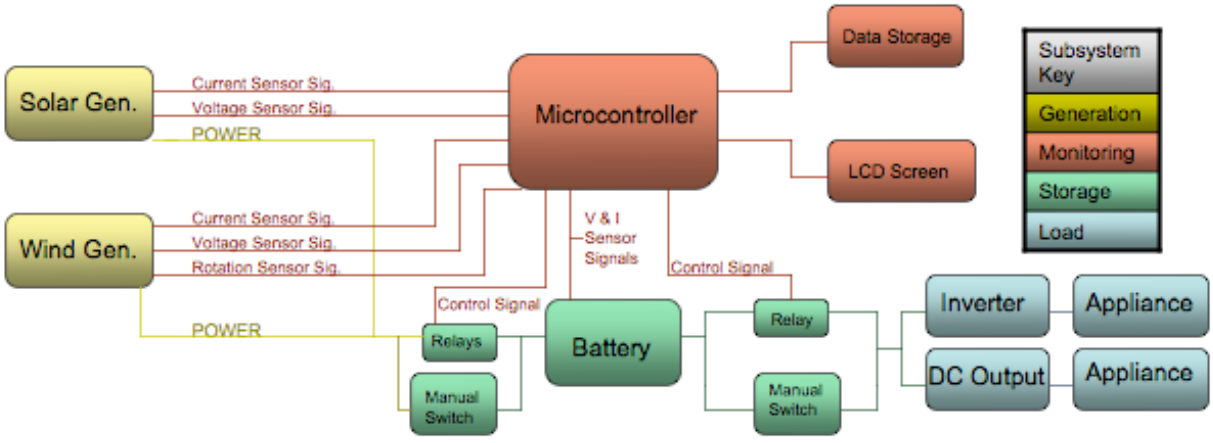


Figure 1. Block Diagram of System

2.3 Generation Description

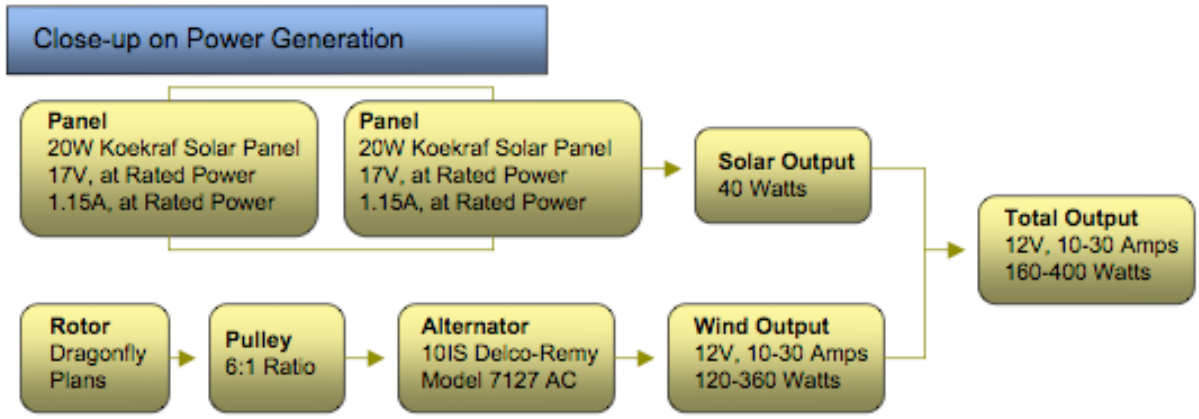


Figure 2: Generation Subsystem

2.3.1 Wind Power Generation

Current developments in wind generation have resulted in a progressive increase in rotor size, resulting in growing and prohibitive initial cost. Since our primary focus is low-cost, not high-efficiency, we'll instead build a low-tech wind turbine to harness the wind. Our wind turbine has three components: blades, nacelle, and structure.

Blades: We managed to acquire a set of blades manufactured by Southwest Windpower for the Air-X design from the ND AME Department that were left over from a previous senior design project. We then bolted the blades to a wooden hub and attached the hub to shaft using two flange bearings.

Nacelle: The nacelle consists of the pulley system connecting the spinning hub to the generator. The rotor and alternator will be connected using a drive pulley with the proper gear ratio to step up the wind speed to the RPM needed for the car alternator. It's theoretically possible to salvage the pulley and belt from an abandoned automobile, and a pulley system is considerably less expensive than a gearbox. For our purpose, we'll be using aluminum V belts and pulleys to avoid corrosion and stress fractures.

To generate electricity, the kinetic source (blades) will drive electric machinery to induce current flow through our charging circuit. The technologies available to us are bike dynamos, DC generators, and car alternators. A DC generator is the most obvious choice for a wind turbine, since it provides direct current that does not need to be rectified to charge a battery. However, DC generators are not readily available in third-world communities. Bicycle dynamos are more plentiful and generally cheaper to obtain. When building his windmill, William Kamkwamba used a bike dynamo purchased under the sponsorship of a village chief. The main downside with bike dynamos is that they usually only generate a few watts of power.

Our best option is using a car alternator for generation. All automobiles built after the

1960s use alternators with build-in rectifiers and regulators. This means if we can provide sufficient RPM to the alternator rotor, the output can immediately be used to charge a 12V battery. More importantly, car alternators can be salvaged from abandoned vehicles, potentially making this otherwise expensive component of a wind turbine free. Even in the famine stricken Malawi, junkyards and landfills can be a potential gold mine for alternators and other material needed for this project.

Car alternators are rated at 30 to 75 amps. Higher rating alternators need a lot of wind before their output reaches what is required to charge their rotor field, so they would not produce any electricity at lower wind. Small alternators (30 to 45 amps) will turn at lower wind speeds, but will have lower output. For our purpose, the lower power alternators have the advantage of higher fill factor and lower cost. The make and model of the alternator is not a significant issue for our situation. We'll be purchasing whichever car alternator is cheapest with a preference for those with low amperage.

After researching the market for cheap, regulated car generator, we purchased the 10IS Delco-Remy Alternator (model 7127 AC). Originally used in GM vehicles, it is one of the cheapest car alternators available in market with build in voltage regulators. It reaches peak output of 63 Amps at 5000 RPM, but begins output power at 1000 RPM. We plan to run it at 3000 RPM using 6:1 pulley ratio, which should output 30 Amps at average wind speeds.

Pulley and Structure: We'll be building the overall structure of the windmill using plywood. While steel provides a sturdier frame, its scarcity and cost makes it a poor choice for rural communities. Wood structures can be reasonably replicated in most poor communities. The blades we are using require a threshold wind speed of 8mph, which is most easily found at some height off the ground. The blades are are recommended to be placed at least 7 meters off the ground in an unobstructed area. For our demo, we could not build a structure quite as large as recommended. Instead we built a short prototype so that the workings of the nacelle could be more easily observed. At this low to the ground, threshold wind speeds are hard to find. With increased height the user will experience better results.

The EmPOWERment prototype turbine is pictured below in Figure 3.

Figure 3: Completed Turbine

2.3.2 Solar Power Generation

After shopping online for appropriate panels, we concluded that most solar panels are too expensive to fit within our budget. We contacted Professor Curt Freeland in the CSE department who has a number of donated Koekraf 20W solar panels that he is not currently using. We are borrowing two 20W panels for this project. The voltage at rated power is 17V, and the open circuit voltage is 22V. The current at rated power is 1.15A.

Throughout the day and throughout the year, the angle of the sun's rays changes. To allow the user to adjust the solar panels for optimal power production, the EmPOWERment prototype includes wooden stands for the two panels. The stands have an adjustable angle and allow the user to prop the stands up off the ground. They are pictured below in Figures 4 and 5.

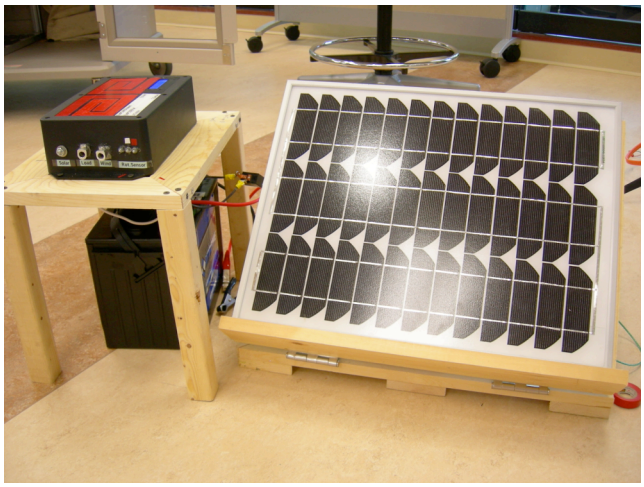


Figure 4: Stand Side View

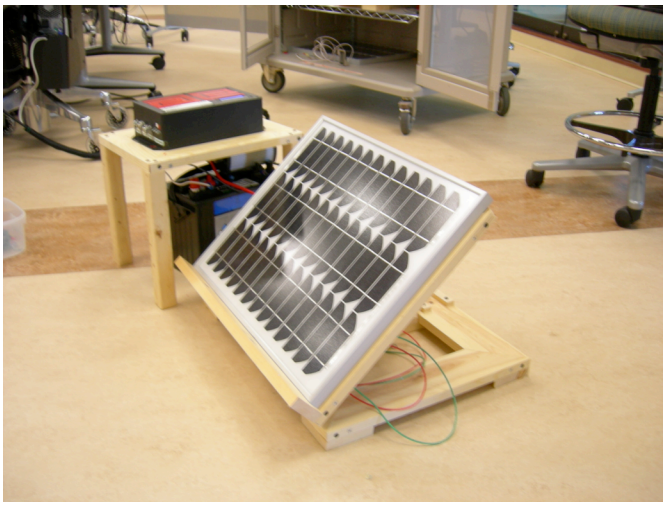


Figure 5: Stand Front View

2.3.3 Power Generation Testing

It is important to know what kind of power the system will produce under various conditions. To a certain extent we tried to conduct performance testing outside using real wind and solar energy. We also needed to conduct testing under more controlled circumstances. To investigate the production levels of the wind turbine, in the fall we connected a 550-rpm motor to the alternator. The motor imitated wind speed, allowing us to determine whether the pulley system we had decided on would be sufficient to drive the alternator. To test the solar panels, we measured the voltage across the terminals when the panels were in full sun. We then connected the panels to a slightly discharged battery to measure the voltage and current being provided by the panels. Our results backed up the Koekraf technical specifications.

2.4 Monitoring and Control

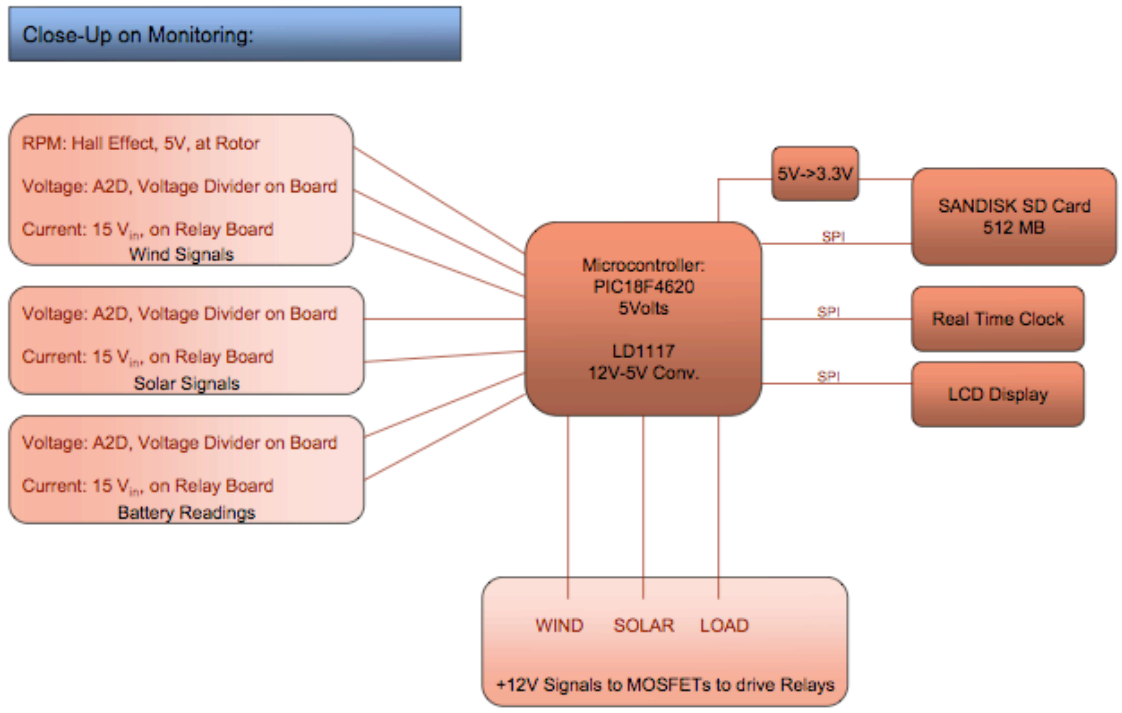


Figure 6: Monitoring Subsystem

2.4.1 Microcontroller: We are using the PIC18F4620 by Microchip. This microcontroller uses flash memory, has 64kBytes of memory, 36 I/O pins, 10-bit A/D, and SPI ability. It has a total of 44 pins, making it simpler to solder than more complicated microcontrollers. This microcontroller runs at 5V, so we have decided to run the entire board that houses the microcontroller at 5V. The battery powers the board, which is 12V. The following table outlines each pin connection.

Table 1: Microcontroller Connections

Pin	Type	Function
A0	A/D Input	Reading from the wind current sensor
A1	A/D Input	Reading from the solar current sensor
A2	A/D Input	Reading from the load current sensor
A3	A/D Input	Reading from the battery voltage
A4	TTL Output	Output to wind relay
A5	TTL Output	Output to solar relay
A6	Ext OSC	Connected to external 20 MHz crystal osc.
A7	Ext Osc	Connected to external 20 MHz crystal osc.
B0	TTL Output	Output to load relay
B1	Digital Output	SPI SS for the SD card (through level shift.)

B2	Digital Output	SPI SS for the RTCLK
B3	Digital Output	SPI SS for the LCD
B4	Unimplemented	
B5	Unimplemented	
B6	Programmer	ICSP programmer to Melabs programer
B7	Programmer	ICSP programmer to Melabs programer
C0	Digital Input	Input to timer1, turbine rotation counter
C1	Unimplemented	
C2	Unimplemented	
C3	Digital Output	SPI CLK signal
C4	Digital Input	MISO, SPI input to the microcontroller
C5	Digital Output	MOSI, SPI output to the slaves
C6	Unimplemented	Parallel display
C7	Unimplemented	Parallel display
D0	Unimplemented	Parallel display
D1	Unimplemented	Parallel display
D2	Unimplemented	Parallel display
D3	Unimplemented	Parallel display
D4	Unimplemented	Parallel display
D5	Unimplemented	Parallel display
D6	Unimplemented	Parallel display
D7	Unimplemented	Parallel display
E0	Unimplemented	
E1	Unimplemented	
E2	Unimplemented	
E3	MCLR input	Master Clear Signal
Vss	GND	Ground reference voltage
Vdd	+5V	High reference voltage and power supply

The pin assignment for the analog to digital conversion dictated for the most part the parameters for assigning the other pins. The first 4 AD channels are correspond to pins A[0-3], and since AD pins must be continuous as determined by the AD configuration register these pins were used for the current sensors and the voltage measurement.

Pin Assignments: AD conversion

Since our measurements are not time critical, the largest parameters for AD conversion time and time division were used in the AD configuration register. Using these parameters minimized noise in the readings. For the current sensor readings, when accuracy depended on the lower bits of the AD output register, we implemented a quasi twenty-bin FIR digital filter that averaged the signal through 20 iterations. The

signal was then translated and scaled into a signed short in order to be able to detect negative currents, making use of the sensor's wide range.
Since a high resistance voltage divider was used, the signal tended to be more stable for the voltage sensor; accordingly the digital filter was unnecessary.

Pin Assignments: Relays
Consecutive pins were chosen for controlling the relays in order to achieve consistency in the design. Setting the tristate of the corresponding pins to 0, we set these pins as outputs. Changing the value store in the latch associated with each pin changes the value of the port.

Pin Assignments: SPI
There are six pins associated with the Serial Peripheral Interface to the LCD, SD card and real time clock (RTCLK). Three signals are shared by all devices: the clock signal from pin C3, master input slave output (MISO) in C4, and the master output slave input (MOSI) in C5. All the devices connected in the SPI interface see these three signals, but only become transparent when the slave select pin is set to the correct position in the slave. Each slave device is connected to an individual slave select in the microcontroller. The default settings for each device differ; accordingly, the code changes the configuration of the master synchronous serial port (MSSP) every time it interfaces with a different device.

Since the LCD has the lowest clock operation speed, a maximum of 400 kHz, we chose the slowest setting for the microcontroller clock speed. By using the microcontroller with the internal oscillator at 125kHz, and configuring the tuning and oscillator registers, we ensured optimal operation of the display. Furthermore, in the MSSP configuration register we divided the F_{osc} by 64 to make a 2 kHz SPI clock speed. Since our application is not time sensitive these settings are appropriate. The LCD slave select needs to be cleared in order to make the SPI signals transparent to this device. For the other two devices the slave select must be 1.

Pin Assignments: Rotation Sensor
Pin C0 was selected to be the input of the Hall effect sensor, because it is already connected in hardware to the timer1 counter registers. Using the timer1 configuration registers, timer1 was set to be fed from an external input, and to have a 1:1 scale factor. Timer0 was set to increment with a frequency of F_{osc} divided by 64. Accordingly, the initial value after each counter overload is set to be 2000 counts less than the full register. In other words, since it takes 2000 oscillations for the timer0 register to overflow starting the interrupt routine that calculates the rotational speed of the turbine, the register is set to 2000 counts less than the full value of the register. This ensures that the counter sec in the code increments every second.

2.4.2 Hardware: Sensors

Current: We are not anticipating having any current much higher than 30A, but the alternator has the ability to produce up to 70A if driven too hard. To provide for that case, we made sure to use current sensors with a wide range. We decided on a Tamura Hall Effect current sensor that can measure +/- 100A. Figure 7 shows the sensor range. Figure 8 is a schematic of the sensor; V_{CC} in Figure 7 is 5V. We are running the power wires through the hole in the current sensors, and the sensor measures the current flowing in the wire. The sensor outputs the current measurement as a voltage between 1V-4V on pin 4, as shown in the diagram below. 2.5V corresponds to 0A, and each +/- .1V corresponds to +/-10A.

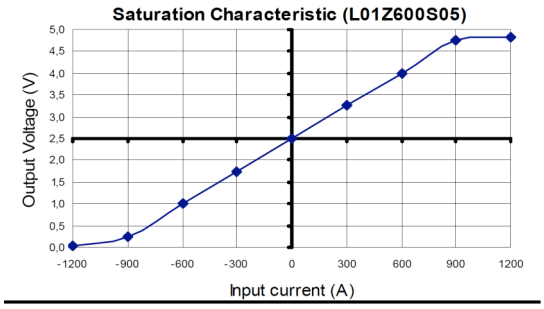


Figure 7: Current Sensor Characteristics

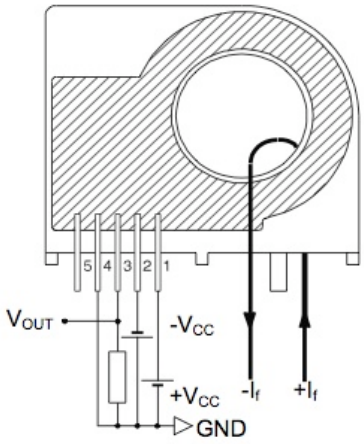


Figure 8. Current Sensor Diagram

The output of the sensors is run through unity gain buffers made from op-amps. This is in order to guarantee signal integrity, particularly since the signal had to travel from the sensor boards to the main board. These sensors have a wider range than our expected currents. This might seem as a disadvantage, however it makes the system more versatile by allowing more powerful wind and solar generators to be connected to the system.

Our system has three separate yet identical current sensor boards, one for the wind cable, solar cable, and cable delivering power to the load. We decided to place each sensor onto its own board to make spacing and wiring within our central system box simpler. The wire carrying the power from the wind turbine and to the load is 10 gauge, making maneuvering difficult. Keeping the boards modular makes the arrangements within the box possible.

Voltage: The voltage sensor uses a 100 k Ohm and 47 k Ohm voltage divider. This allows for a sensing range from 16 to 0 volts, which correspond to 5 and 0 volts output voltages respectively. The high resistance makes power dissipation minimal. Higher resistances however might not provide enough current to the AD converter to work effectively. A future improvement for this system could be a unity buffer between the voltage divider

and the microcontroller. However, since the variance of this signal is so low and the impedance of this channel so high the current implementation works fine.

RPM: To record wind speeds and rotor speed, we ordered an Infineon Hall effect Sensor. This sensor requires 5V to operate. The alternator cannot consistently power the sensor because when the relay is off, the alternator will not produce voltage. We would like to measure RPM continuously, not just when we are charging the battery with the energy produced by the turbine. Particularly, the sensor helps to establish if the turbine is rotating above a threshold of minimum RPMs before powering the coils of the alternator. This helps the turbine reach an optimal rotational speed before powering the coils in the alternator. We plan to wire 5V, a GND, and a signal wire out from the microcontroller board to the Hall effect sensor board. The hall effect sensor board will be located out at the wind turbine.

We used a Schmitt triggered unipolar Hall effect sensor that responded only to the presence of a north pole. The Schmitt trigger reduced the amount of noise in the output, and prevented false-positives. The output of the sensor was an open drain connected to a unity gain buffer that ensured signal integrity for the long journey to the system.

We have secured a powerful magnet, 1800 gauss, to a blade of the turbine. The Hall effect sensor is mounted on a 1 inch^2 board close to the rotor, so during each revolution the magnet passes close to the sensor. Every time a magnet passes by the sensor, the sensor triggers.

Testing Plan: The current and voltage sensing systems can be verified by using a functional multimeter to double check the found values. The Hall effect sensor can be checked by using a strobe light to measure the win turbine RPM.

2.4.3 Hardware: LCD Display/User Interface We are using an LCD screen with an SPI Interface from Newhaven Displays. The screen has optional colored LED backlights and runs at 5V, which is convenient for our board design. Our board includes the capability to also run a parallel LCD. We left both options open, but ultimately decided on SPI for our final prototype because it uses fewer pins. The simpler design was attractive.

We considered including buttons to allow the user more interaction with the system. In the end we did not include buttons because we wanted to keep the system simple. The added user involvement seemed unnecessary given the philosophy behind our project.

Figure 9: LCD Display

Testing Plan: We will display the values read from the sensors on the LCD screen. Because the LCD displays only two lines at a time, the display will cycle through the information.

2.4.4 Hardware: Data Storage

While it is nice for the users to see in real time the electric production and consumption of their EmPOWERment system from the LCD display, the data will be lost without having a storage option available to the microcontroller. If a storage option is available, the data collected by the various sensors can be analyzed at a later date and evaluated over a longer time range without the limitations inherent to a microprocessor system. This benefit leads us to look into storage options that are available to us, and we determined that the Secure Digital Card (SD Card) storage format is the best option for our project.

As the most popular storage medium for consumer gadgets such as cameras, phones, and music players, the SD Card offers a low cost, high capacity, and wide availability option for data storage. Furthermore, the SD protocol is widely documented and offers compatibility with the comparably simple SPI protocol. We also benefit from the fact that our microprocessor has an MSSP module that has a hardware implementation SPI protocol, which further reduces the software overhead required for storage.

Our controller receives data streams from six one-byte analog sensors, one two-byte RPM sensor, and three sets of relay control. Therefore our controller generates data at the maximum rate of about 150 bytes a second, or about 13 MB a day. We expect the longest period we will collect to be no more than a month, thus a 512 MB SD Card should be more than sufficient for our usage.

In order for the data we collect to be usable, we have to choose a file system that can be read on a personal computer. We chose the FAT format since Windows, Macintosh, and Linux OS support it. As an older file system, it is simpler to implement due to the

lack of modern error correction system. Since our data are not critical in nature, that is not a major issue, and the time saved can be utilized elsewhere to improve our project.

Since the SD card runs at 3.3V and the rest of the system logic runs at 5V, we had to implement a 3.3V voltage regulator, and a voltage level shifter. The voltage regulator was placed in cascade after the 5V regulator. This ensures that the input voltage is above the minimum threshold specified by the LD1117 3.3 regulator. It also ensures that the 3.3V regulator is protected by the 5V regulator. The Maxim3378 level shifter fit our needs with a 5 line conversion: one for the slave select, one for the clock, one for the MISO, and one for the MOSI. Since the SPI clock signal was at its lowest speed, and the level shifter had a wide range of operational frequencies, speed was not an issue.

A real time clock was included in the design primarily to aid in data collection. The real time clock works by receiving the oscillator frequency from a 33 MHz external ceramic resonator. It interfaces with the microcontroller through the SPI interface. However, not all of the functions of the RTCLK were implemented. Particularly, the it has alarms which can set interrupts and change certain pins that can be connected in the microcontroller. These could have been used to get the sunset and sunrise time in the microcontroller code. However, the current implementation is more efficient with regards to the pin distribution; furthermore, it allows a function to calculate the sunrise and sunset times depending on the time of the month. We fixed two mistakes in the schematics Vbat, the input voltage for a support battery, and Vdd2 were both grounded. They were previously left unconnected and connected to Vdd respectively. In the prototype we fixed these problems by severing the copper lines, and routing the pins to the ground using a thin wire.

2.4.5 Software

The software interfaces with the user in both English and Spanish, extending the range of locations where our system can be deployed. Other languages that can easily be implemented include French, Portuguese, and Quechua, reaching 1.5 billion people all around the globe

The software was developed in separate libraries that contained functions for the different subsystems. These libraries include: an SPI LCD library based on the parallel LCD library provided by Dr. Schafer, a RTCLK library, a relay library, an analog to digital conversion library to handle the current sensors and the voltage sensor, and a rotation sensor library. All of these libraries include initialization routines for the different devices. The following is a brief overview of the flow of the code and a description of the contents of each library. The full body of the software is available in Appendix B or on the project website.

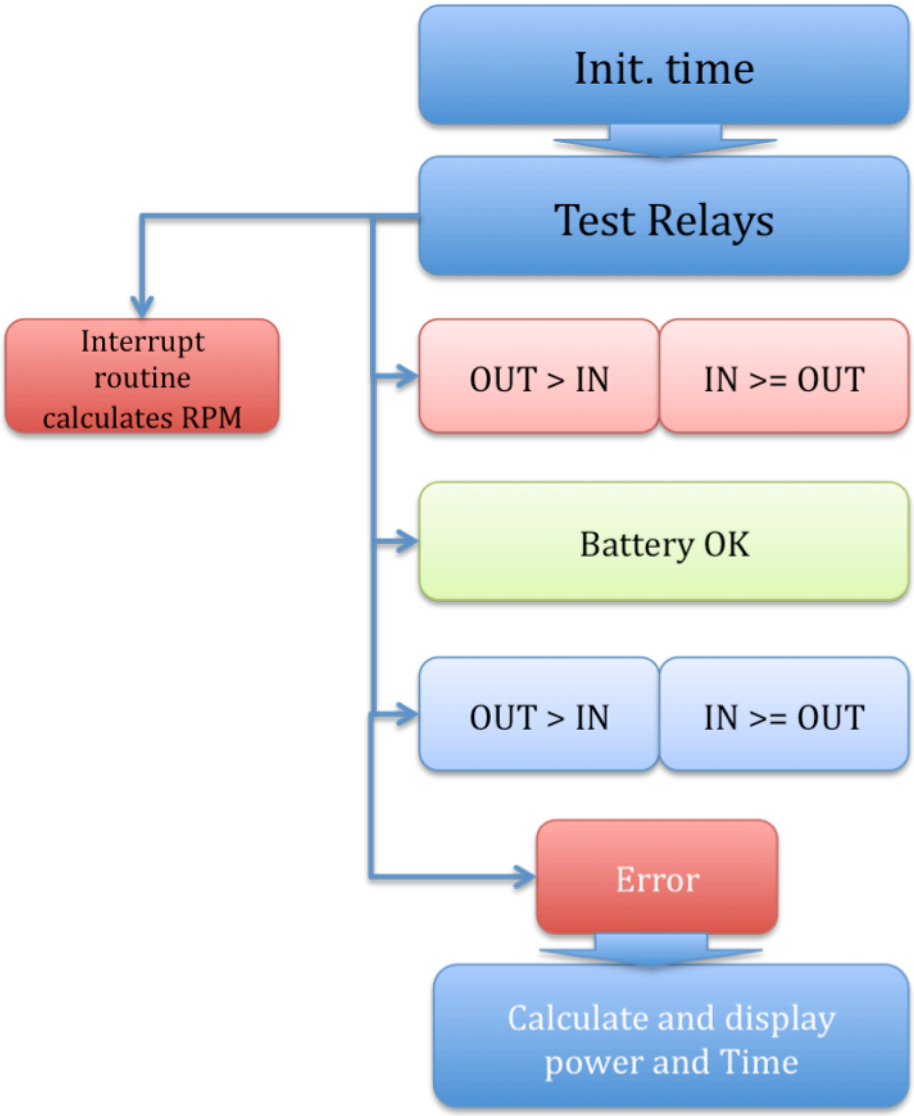


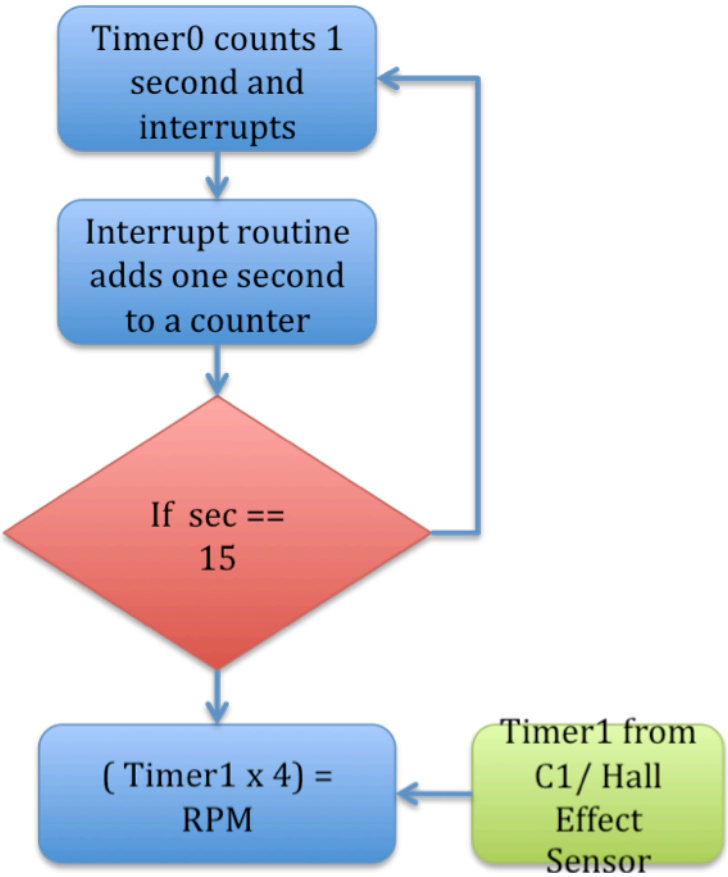
Figure 10: Main Code Flow

RTCLK Library

The real time clock library defines a time struct that holds all of the data in binary decimal coding. It has a primordial function writeSPIRTC that writes and reads characters to the real-time clock. The init function sets the MSSP to the proper parameters. Write and read functions use a write register function to get and set the time in the real time clock. A function calculates the sunrise and sunset depending on the month of the year. These values are based on the global averages available for South Bend. In future implementations, a user interface using a keyboard could be used to set the initial time, as well as communicate the latitude where the system is deployed. This way the system can accurately operate the solar panels only during daytime. GPS could be another possible addition; however, the price of the system will increase, making it less accessible to impoverished communities.

Relay Library
Setting the appropriate port tristates to outputs initializes the relays. The wind relay can only be turned on when the velocity of the turbine is above 20 rpm. The solar relay can only operate during daytime. The sunset, sunrise, and current time are passed onto this function.

A2D Library
The parameters for AD conversion have been previously described. The initialization function sets the appropriate values in the adcon register. The functions return the values of the AD conversion after they are translated and re-scaled. The results short signs; however, these functions print the values of these conversion to a decimal accuracy.


Timer0 counts 1 second and interrupts
Interrupt routine adds one second to a counter
If sec == 15
(Timer1 x 4) = RPM
Timer1 from C1/ Hall Effect Sensor
Figure 11: Interrupt Routine

Rotation Sensor Library
The rotation sensor initializes the interrupt configuration registers and starts the timers: timer1 and timer0. The actual calculation is performed by the interrupt routine, pictured above in Figure 11.

SPI LCD Library
The SPI LCD contains an initialization function that sets the MSSP to the correct settings. Most of this library was constructed upon the parallel LCD library provided by Dr. Schafer. There is also a function that reads the time struct pointers. This function serves to print the current time.

Main code
The main code contains an initialization routine that checks the relays by switching them on and off, letting the user know that they are operational. The sensors are read, and depending on the values of current input and output and the voltage of the battery the system enters into three main states.

1-Battery full
If the battery reaches 14 volts, but the current output is greater than the inputs, it will turn on the inputs so the battery is not drained. Otherwise the battery can only provide energy.

2- Battery OK
If the battery voltage is between 14 and 10 volts, all of the relays are on.

3- Battery Discharged
If the battery reaches 10 volts and the inputs are greater than the outputs, the outputs are connected allowing critical applications to continue working while protecting the battery from deep discharging. Otherwise the inputs are on and the outputs are off.
Nota bene: there are switches that the user can turn on to bypass the relays. Since this defies the purpose of the system these switches are only accessible after opening the box.

Power Calculation and Display
The code calculates the power consumed and generated and displays it to the user. It also displays the speed of the rotor and the current time.

2.5 Storage

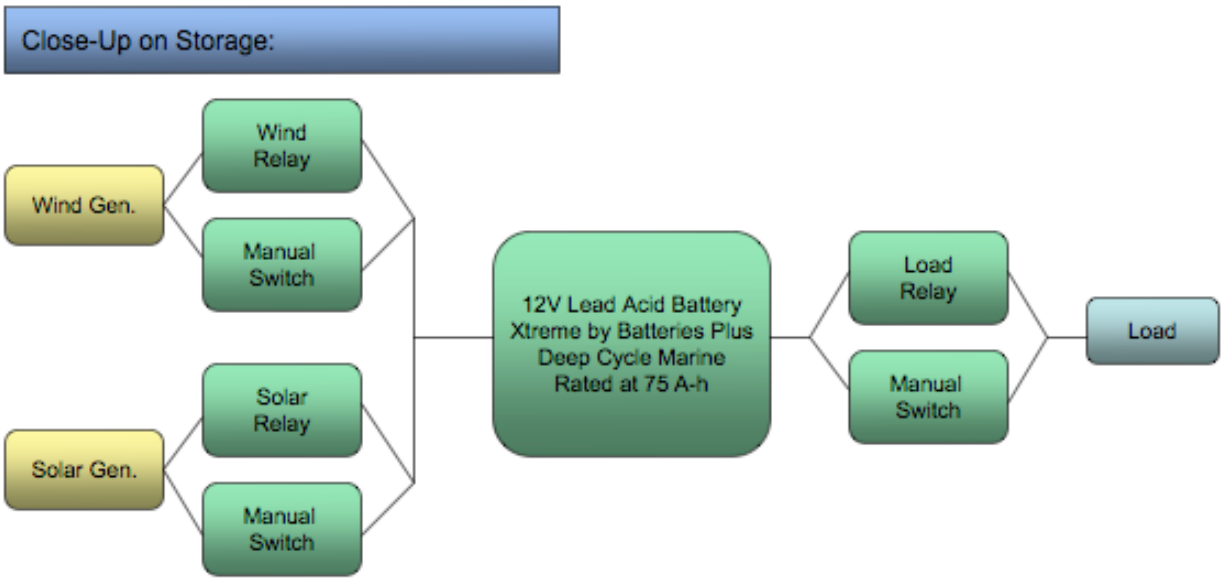


Figure 12: Storage Subsystem

2.5.1 Battery: Because we are looking for a cheap, easy-to-find battery, we are using a 12V lead acid battery. These batteries are very widespread since they are used in many applications, most notably automobiles. These batteries also prefer to be float-charged, which is how our system will do most of the charging. During testing, the likelihood of deep discharge for the battery is very high. With a normal 12V lead acid battery, 5 or 6 deep discharges can irreparably damage the battery. To avoid this we invested in a deep discharge battery designed for marine applications. Once testing is complete and the danger for deep discharge has been mostly eliminated, a normal lead acid battery could be substituted. We have purchased an Xtreme Batteries Plus 12V battery rated at 75 Amp-hours.

We have not fully determined the best method to connect the battery to the rest of the system. Power cords from the generating subsystem run into the main system box, where the voltage and current is monitored. Then it is delivered to the battery, which is housed outside of the main box.

Testing Plan: We would like to investigate the capacity of our battery. The rated capacity may not reflect the real physical behavior. This will be done by slowly charging the battery to full charge. Then we will drain the battery at a constant load, monitoring the current and voltage the entire time. We will time how long it takes the battery to reach deep discharge. These practices will help us to determine the real capacity.

2.5.2 Relays:
The main role of the relays is to protect the battery from over- or deep discharging. These relays are designed for automotive use, so they are well equipped to be switching

the voltage and current associated with charging a 12V lead acid battery. These relays are capable of switching 40A, which is higher than our expected current for anywhere in the system, and operate at voltages up to 12V. It should be noted that the relays are the component that limit the amount of current the system is able to handle. If this system is revised to include a more powerful alternator or wind turbine, the relays will need to be updated. They also have a built-in surge-absorbing diode to protect the relay from the large EMF that occurs when it is switched into the disconnected position. As an additional protection, we soldered diodes across the coil terminals of each of the relays. The packaging is conveniently compact, saving space within our system. We have chosen the chassis mount model to allow for easy mounting within the system box. The rated operating current is 117mA, making their operating power consumption around 1.4W. This power will be consumed when the relays are driven by the microcontroller. At extremely low battery voltage, the relays will go back to their default connected position. However, the battery protection built into the inverter should prevent the user from further damaging the battery.

To drive the relays, we are using Fairchild NDS355AN transistors as switches. One of the main applications for these transistors is driving relays. For a V_{GS} of 4.5V, they produce an I_D of 1.7A. The relays require 117mA to operate, so this I_D is adequate. The microcontroller will provide the V_{GS} to the FET to then switch the relay. Each transistor consumes .5W.

The relays are mounted separately from the rest of the components. We made this decision because we want to keep the wires carrying the main power away from the board with sensitive components on it, and also for greater flexibility during assembly We are connecting the relays to the current boards using spade lugs. The connection is necessary in order for the microcontroller to control the opening and closing of the relays.

During the testing process we connected the battery using the wrong polarity, which forced too much current through these protection diodes subsequently destroying them. As a result we reverted to using unprotected relays to which we soldered some protection diodes. This incident also led to the disabling of port A5. Accordingly we had to route port D6 to the solar relay. In order to prevent this from happening in the future, particularly as our intended clients are not technologically savvy, we placed a protection diode between the input of the battery to the system and the switch that turns on the system.

Testing Plan: To test this set-up, set the circuit up so that the relay connects a 12V battery and the motor. A test program in the microcontroller sends a signal of 0V to the gate of the driving MOSFET for ten seconds, and then sends a positive signal for 10 seconds, switching back and forth. If the motor first runs, corresponding to a 0V signal, and then stops for 10 seconds, corresponding to the positive signal, the relay system is

working correctly. In the final system, the relays will be triggered if the battery falls below 10V, goes above 14V, or when the alternator is just starting up.

2.5.3 Switches: In case the user would like to override the microcontroller and the relays, three manual switches will allow the user connect and disconnect the battery to and from the generating subsystem and the load. These switches will be connected in parallel with the relays.

2.6 Load

DC-AC Inverter: Two main types of inverters are available on the market. Modified sine-wave inverters are an inexpensive option, usually costing $.05-$.10/Watt. This type of power has a total harmonic distortion (THD) of about 25%. A modified sine-wave inverter works great for electronics like TV's, most lights, microwaves, and many tools. However, modified sine-wave inverters are unsuitable for sensitive electronics like computers, stereo equipment, some kinds of fluorescent lights, and some medical equipment. For average home use, a modified sine-wave inverter would suffice. If a medical center, school, or business wants to use the system to power computers or medical equipment, though, a pure sine-wave inverter is necessary. Because we are operating under a small budget, we have decided to purchase a modified sine-wave inverter for the prototype. If these systems went into production, emPOWERment would most likely offer two product levels, one for home use and one for office/medical use.

The inverter we have selected is the CPI-480 by Cobra. This inverter has 400W continuous, with 800W surge. It has two AC outlets for the user to power appliances with. It has a very low no-load current draw of <.5A. The efficiency is about 88%, which is fair for its price range. It also has an automatic shutdown at a battery voltage of 9.5V. Providing 400W to this inverter would require about 30A from the battery. A fully charged battery with no contribution from the energy generation systems could provide 400W for about .93 hours. Or, for a more realistic example, the system could power a 100W 19" color TV for about 3.75 hours.

Figure 13: Inverter

Pictured above in Figure 13 is the inverter in EmPOWERment's prototype. The inverter is mounted underneath the system box, above the battery.

2.7 System Housing and Construction

The main system box is a 10″x6″x3″ Polycase box. This design was chosen for its large size and durable material. We cut a rectangular opening in the lid of the box for the LCD screen to fit through. The seam was weatherproofed with hot glue and covered in electrical tape for a clean finish. The cover of the box is decorated with a traditional Colombian design, shown in Figure 14.

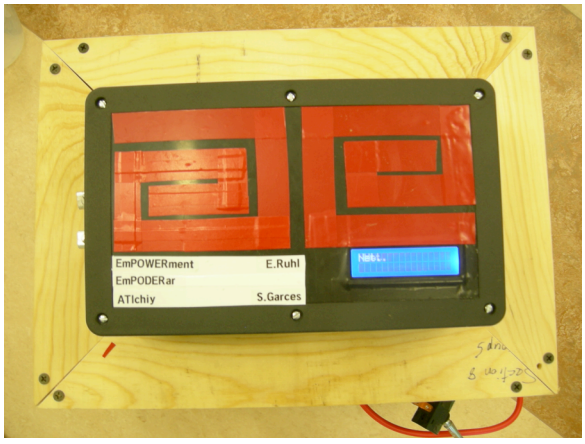


Figure 14: System Box, Top View

One side of the box contains the main connections between the power generation sources, load, and rotation sensor board. These connections were made by drilling into the side of the box. The two connectors for the high current carriers, or the positive wind terminal and the positive load terminal, are aluminum splices from Lowe's Hardware. The other connectors are simply metal screws and washers. Figure 15 shows these connections.

Figure 15: System Box Side Connections

The battery connects to the board from below. The system box is designed to sit on a frame that covers the battery. The prototype frame is made from wood. The power from the battery connects to the box through an aluminum splice. The negative terminal of the battery provides the common ground for the entire system, including the negative terminals of the power generation and the load. All four negative/GND leads connect to the box from beneath through an aluminum splice. Figure 16 shows the main system box screwed onto its stand and connected to the battery from below.

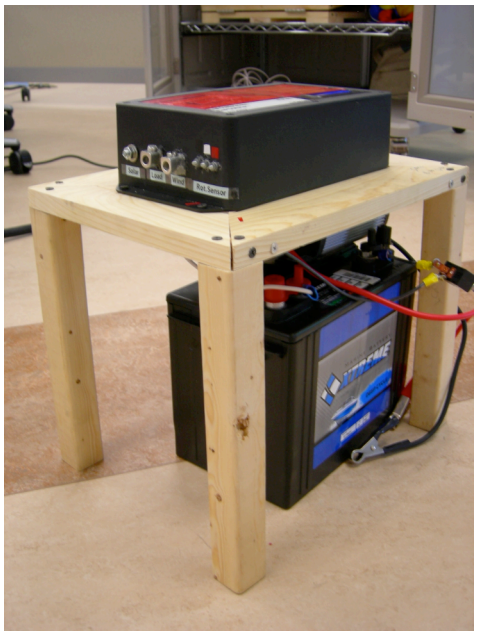


Figure 16: System Box with Stand

The Hall effect sensor board is housed out at the turbine by a recycled Coca-Cola plastic bottle. The original polycase box we ordered for the housing interfered with the sensors detection abilities, so we got creative. The thin plastic housing is secured to a piece of balsa wood using a variety of adhesives.

All connectors in the side of the box were weatherproofed with hot glue. They were also labeled and color-coded for the user. All connections were made with either Molex connectors or crimp-on spade lugs that were then protected with heat shrink and electrical tape, depending on what materials were available during the time of construction.

3 SYSTEM INTEGRATION

3.1 Testing Methods

Testing procedures for individual components are included in the previous section as each component is described. When putting the entire system together, we started slowly, adding one component at a time until the system was complete.

Our first steps in testing centered around making sure our newly soldered boards functioned as we expected. Initially we verified that our microcontroller and main board was working. We did this by running a test program that displayed various test values on the SPI LCD. Next we verified that the current sensor boards were functioning by running wires with test currents through them and displaying the output with the microcontroller and LCD. We double-checked the values found using an ammeter. The next step was adding the relays to the circuitry and making sure the microcontroller could control them. We simulated threshold battery voltage readings in

the test code, and the relays opened and closed accordingly. Finally, we connected our Hall effect sensor board to the main board and simulated the blades rotating by moving a magnet across the sensor. The SPI LCD reported an approximate rpm for the movement of the magnet.

Next we made sure our power sources were functioning. We had previously checked the solar panels in the sun, and we knew that the panels' performance followed the technical specifications. We had checked the alternator's performance in the fall demo and knew that if the alternator could reach its threshold rpm it would produce electricity. We could not simulate threshold wind speeds in the Learning Center or find threshold wind speeds reliably outside, so we had difficulty testing the effectiveness of the turbine. On the day of the demo the turbine reached high speeds and succeeded in producing electricity, so we verified that with suitable wind speeds the system is fully functional.

With the circuitry fully working and the power sources producing electricity, we had great confidence in the functionality of the system. At this point we connected the inverter to the system, and then connected an AC load. The load drew current, displayed both by the LCD and the fact that the speaker system we had plugged in was playing music. Our testing was complete.

3.2 Fulfilling Requirements

The finished prototype met most of the initial requirements. At full wind and sun, the system produces 400W. The power produced by the power generation sources charges the battery. The monitoring system protects the life of the battery through the use of voltage detection and relays. The monitoring system also provides vital system information to the user in both English and Spanish. Both DC and AC output are available to the user, allowing the user to power a wide variety of useful devices.

The entire system is simple, and it is made from easily found and replaceable components. For example, the wind turbine is made primarily from wood, with the inner workings of the nacelle being constructed from a car alternator and a system of pulleys instead of harder to find DC generators or a fixed gear system. 20W solar panels are becoming increasingly popular and easy to find, even in developing countries. Many solar panels can be found in developing countries, like Kenya and India, which have been made locally, thereby dropping the price. The system remained very modular, allowing the user to substitute in various power sources, battery types, and inverter models.

One goal we did not meet was the use of an SD card. Our main board has the hardware and connections necessary to at some point accommodate an SD card. EmPOWERment could not finalize the necessary software to store the information being gathered by the microcontroller. The final system box layout allows for access to the programmer

pinheader so that the microcontroller could at some point be updated to use the SD card.

4 USER'S MANUAL

At its most basic level, the final system that would be ready for distribution would consist of the main system box with an inverter. The user would be responsible for supplying the power sources, the 12V battery, and all appliances. As the organization expands, more products would become available. For example, once it optimized a design, EmPOWERment could start manufacturing small-scale wind turbines for use with the systems. Alternately, EmPOWERment could sell photovoltaic cells or batteries. Initially though, or at least until EmPOWERment could provide the elements more cost effectively than the user could, EmPOWERment would provide only the system box and encourage the user to find all other elements locally.

4.1 System Installation and Set-Up

4.1.1 Additional Hardware Selection

The system can take up to two power sources. Each power source needs to provide at least 12V-DC for effective charging of the battery. The power source should not provide more than 17V-DC. Too large of a voltage difference between the sources and the battery could harm the battery, while too little of a voltage difference will take a very long time to charge the battery. The power sources should also ideally be regulated to protect the battery and the system.

The EmPOWERment prototype made use of two types of power generation, namely two photovoltaic cells connected in parallel and a homemade wind turbine. EmPOWERment recommends a similar set-up if possible. Using two power generation sources greatly increases the capacity and improves the overall performance of the system. Choosing the location for both wind turbines and solar panels is an important decision. Placing these generation sources in areas that receive ample sun and wind is key. Spend time considering the area available before breaking ground on any construction.

The system is designed to charge a standard 12V lead acid battery. Lead Acid is ideal because the embedded intelligence is designed to follow ideal lead acid charging behavior. Other 12V battery types will function, but the system might not be as effective at preserving battery life.

4.1.2 Connections

For visual reference, turn to Figure 15 on page 28.

When connecting the output of the power generation sources to the system box, make sure to use an appropriately gauged wire. This will depend on the amount of current each source is anticipated to produce. In general, DC current requires a thicker gauge than AC current. In the EmPOWERment prototype, the wind turbine produces around

30 Amps at average wind. The connection between the alternator in the turbine and the system box was made with 10 gauge wire. The solar panels, on the other hand, produce only 1.5 Amps, so their connection was made with 10 gauge wire. To connect the power sources to the system box, connect one end of an appropriately sized wire to the positive output of the power source, and then insert one stripped end into one of the power source screw terminals and firmly secure using a flat-edge screwdriver. Connect another wire of the same size to the negative output of the power source and connect the other stripped end to the common ground screw terminal located on the underside of the system box. Repeat these steps for the other power source.

The EmPOWERment prototype wind turbine had a Hall Effect Rotation Sensor installed in order to measure wind speeds. The sensor receives power from the main microcontroller board, and the signal from the sensor needs to be relayed back to the board. To connect the sensor to the main board, use three small wires, ideally color-coded red (power), black (ground), and white (signal). Connect one end of the wires to a Molex 3-pin connector. The Molex connector latches to a matching piece on the Hall Effect Sensor board. Run the wire back to the system box and insert the appropriate stripped wire into the three provided screw terminals.

The positive lead from the inverter is color-coded red. It connects to the screw terminal labeled "Load" on the connection panel of the system box. The negative lead is color-coded black, and it connects to the common ground screw terminal located on the underside of the system box.

The connections between the battery and the system box occur on the underside of the box. Use a thick gauge wire to be safe. Connect the positive terminal of the battery to the screw terminal color-coded red. Connect the negative terminal to the other screw terminal. The polarity of the battery is very important; avoid wiring in the connections to the battery backwards. Also take care to not short the battery, i.e. connecting the negative directly to the positive terminal. This is dangerous and harmful to the battery.

It is recommended to connect the battery last. Once the battery is connected, the system should begin to operate. The system box should arrive fully assembled and ready to run as soon as all external connections are made.

4.2 Everyday Use

Once the external connections are made, the system is designed to continue to run without repeated disconnections and connections. The LCD displays important information to the user at all times. The microcontroller and relays control connections between the battery, power sources, and load. Switches inside the system box exist as a last resort for extreme circumstances.

The display cycles continuously through a set of important information in both English and Spanish. The LCD displays the speed of the turbine blades, the power generated

by the turbine, the power generated by the solar panels, the power consumed by the load, the remaining charge on the battery, and the date and time.

By checking the LCD, users can keep track of the average power output of their system. If a user checks consistently, then the user will notice quickly if the system is producing less power than usual. The user can then promptly visit the power production sources and perform maintenance or adjust position as necessary.

Checking the LCD often can also aid users in taking care of their battery. For example, the display shows how much power different loads draw. A user can then budget their battery life better, perhaps choosing to use a light for four hours instead of a power intensive refrigerator for only two, depending on the initial battery charge. Familiarity with usual battery life can also help a user to identify when a battery has reached the end of its life and needs to be replaced.

The included inverter is ideal for any appliances requiring AC power. The inverter included in the EmPOWERment prototype takes US plugs. However, the inverter could easily be changed to be appropriate for whatever plugs are common to the user. For appliances requiring DC power, the battery terminals remain exposed for easy access. A simple set of leads from the positive and negative terminals of the battery would be easy to build if DC appliances are common for this user.

4.3 Troubleshooting

In general, if any component in the system quits working, double-check all connections. The system is designed to spread over a long distance connected only by wires, and it is very likely that wires will become worked loose over time. Re-screwing wires and checking connections will most likely go a long way in trouble-shooting any problems. The rest of these troubleshooting tips assume that all connections have been secured.

If the LCD shows that one or both of the power sources is not producing energy when they clearly should be (i.e., turbine turning, bright sunshine), or the load is not consuming energy when it clearly is, check the energy production sources and the loads themselves. If the sources appear to be in good working order, the problem could lie within the system box. For example, the current sensor or microcontroller pin reading the sensor could have broken. If this is the case, the system should continue to charge the battery. The system will simply cease to display generation statistics for that power source. The user should verify that the battery continues to appear charged over a period of days.

The LCD refusing to light up could indicate either that the LCD is broken or that the entire microcontroller and circuit is broken. One way to check is to first disconnect the battery and open up the system box. Reconnect the battery and listen for the clicking of the relays initializing. If the relays click, then only the LCD is broken and the rest of the circuitry is working. The system remains operable, if a little inconvenient to use. If the

relays are silent, then the entire board is likely broken. In this case, the user may continue to use the system by manually connecting and disconnecting the switches connecting the battery to the power sources and the load.

If the user notices the battery refusing to hold a charge, it could be time to reinvest in a new battery. Batteries have a finite lifetime and will likely need to be replaced many times over the lifetime of the system. If the user notices the power sources producing poorly, the user should reanalyze the locations of the sources, or perhaps consider upgrading to a higher efficiency solar panel or more sophisticated turbine design.

5 CONCLUSIONS

5.1 Results

Overall, we are pleased with the results of our system. By the final demo the system met all of the initial requirements except for data storage capability, and that capability remains a possibility for the future. At the demo all aspects of the project performed smoothly. The only aspect of the demo that could have been improved was wind speeds. Because our prototype turbine was so low to the ground, very high wind speeds are required to start the alternator. The wind speeds were not often high enough to generate electricity. The wind was often strong enough to turn the blades without the alternator, and at one point was strong enough to turn the alternator.

5.2 Future

While we are pleased with the system's performance, there is plenty of room for improvement in our design. If we had another year to modify the prototype, we would likely start with implementing the SD Card, improve the user interface, optimize turbine design, and refine the business model of the system.

Our original goal of using the SD card to store power generation and usage data remains. Analysis of that stored data is invaluable in optimizing the system. After installing the SD card, we would ideally like to start some sort of long term testing procedure to gather data over a period of weeks. This data would also help us determine the overall usefulness of the system.

The way our system works now, the LCD scrolls constantly whenever the battery is connected. This is a drain of energy. With an improved prototype, we would look into adding buttons or a switch to turn the display on instead of having it on all the time. With the added feature of buttons, the user interface could also become more interactive. Users could select the value the want to view instead of waiting for it to scroll through. With buttons the user could also reset the time and date of the real time clock.

Throughout the design process, we debated how technologically advanced to make the system. With greater complexity comes better performance, but also increased cost and

greater chance of failure later on. However, one technical improvement whose advantage could outweigh the risk is adding a GPS unit to the system. A GPS system could calculate the sunrise and sunset times for any location in the world. The sunrise and sunset times in the prototype are hardcoded for South Bend, IN. GPS capability adds to the flexibility of the system. Another possible improvement is adding Zigbee communication between the microcontroller and the rotation sensor in order to minimize long, inconvenient wires stretching between the two systems. A power cable will always be necessary, but reducing the number of wires could be convenient.

Our turbine as we built it is fairly primitive. It sits low to the ground and does not rotate in order to always be facing the wind. We also decided to use manufactured blades in order to save time. A second prototype would include a second approach to building a turbine that is taller, that rotates, that produces at lower wind speeds, and that uses hand-made blades instead of manufactured blades.

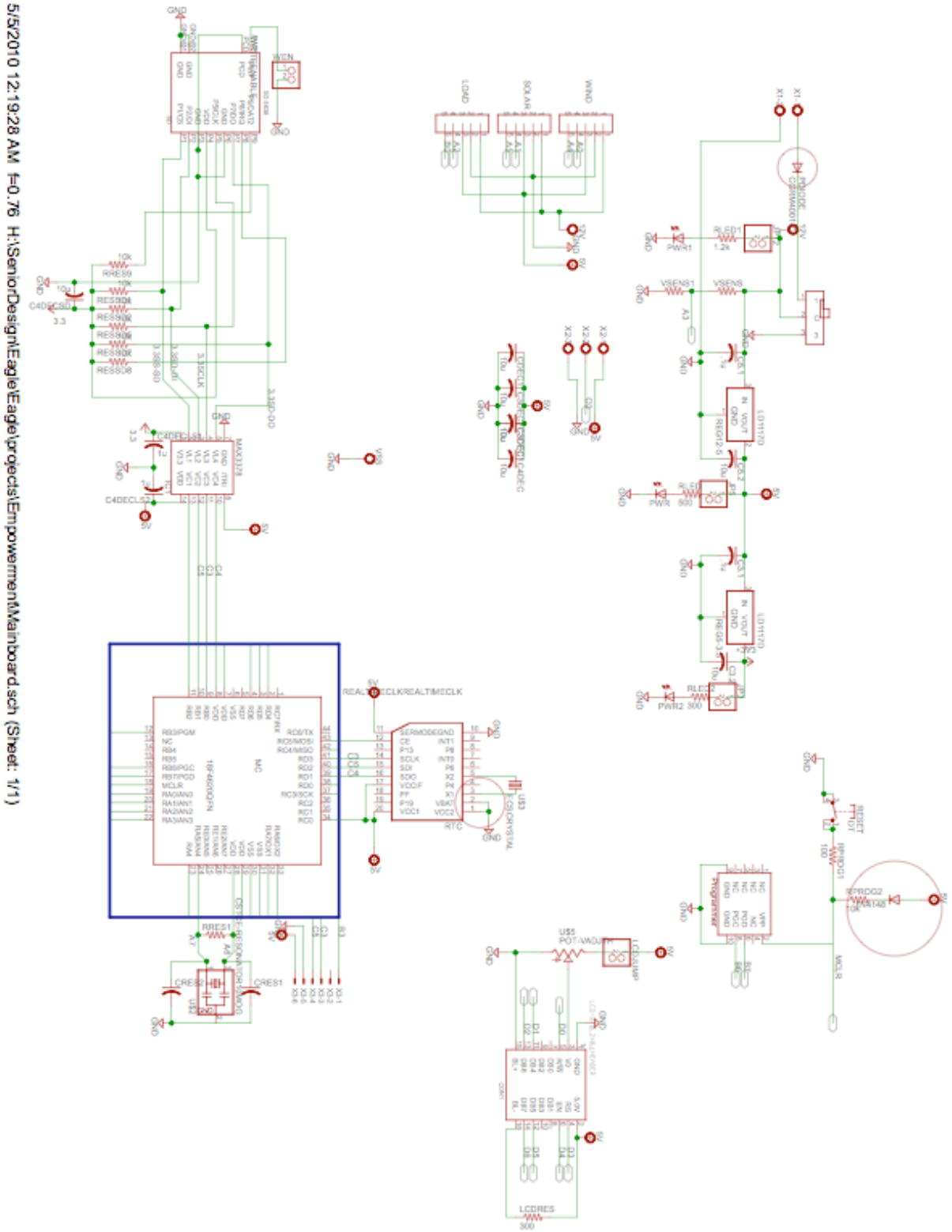
One of the things that got us the most excited about this project is the possibility of refining the system and distributing it. The current prototype is far from being ready to be manufactured or distributed, though. In addition to technical questions remaining unanswered, there are many business-side decisions still to be made. For example, while we have a general idea of what EmPOWERment would theoretically distribute, the total system components have not been finalized. Perhaps it would make more sense to sell the system box along with the power generation sources and a battery. Our thoughts now are that users would be resourceful enough to find the remaining components if they could only buy the system box, but perhaps the convenience of buying a complete system would outweigh any cost savings. Determining what a complete system would consist of is key before nailing down a cost estimate. Figuring out the financials also involves deciding how the systems would be manufactured. Another major missing piece of the plan is how the systems would be sold and distributed. Before being pursued seriously, the venture would need to have solid financial predictions and a possible plan for distribution.

Even with all of these unanswered questions, we think that we have come a long way this semester toward reaching a tangible solution. The project has a lot of potential and possibility for another group of students, either as a senior design project or simply an independent research project. We hope that the work continues on, and that at some point this project contributes to empowering homes around the world.

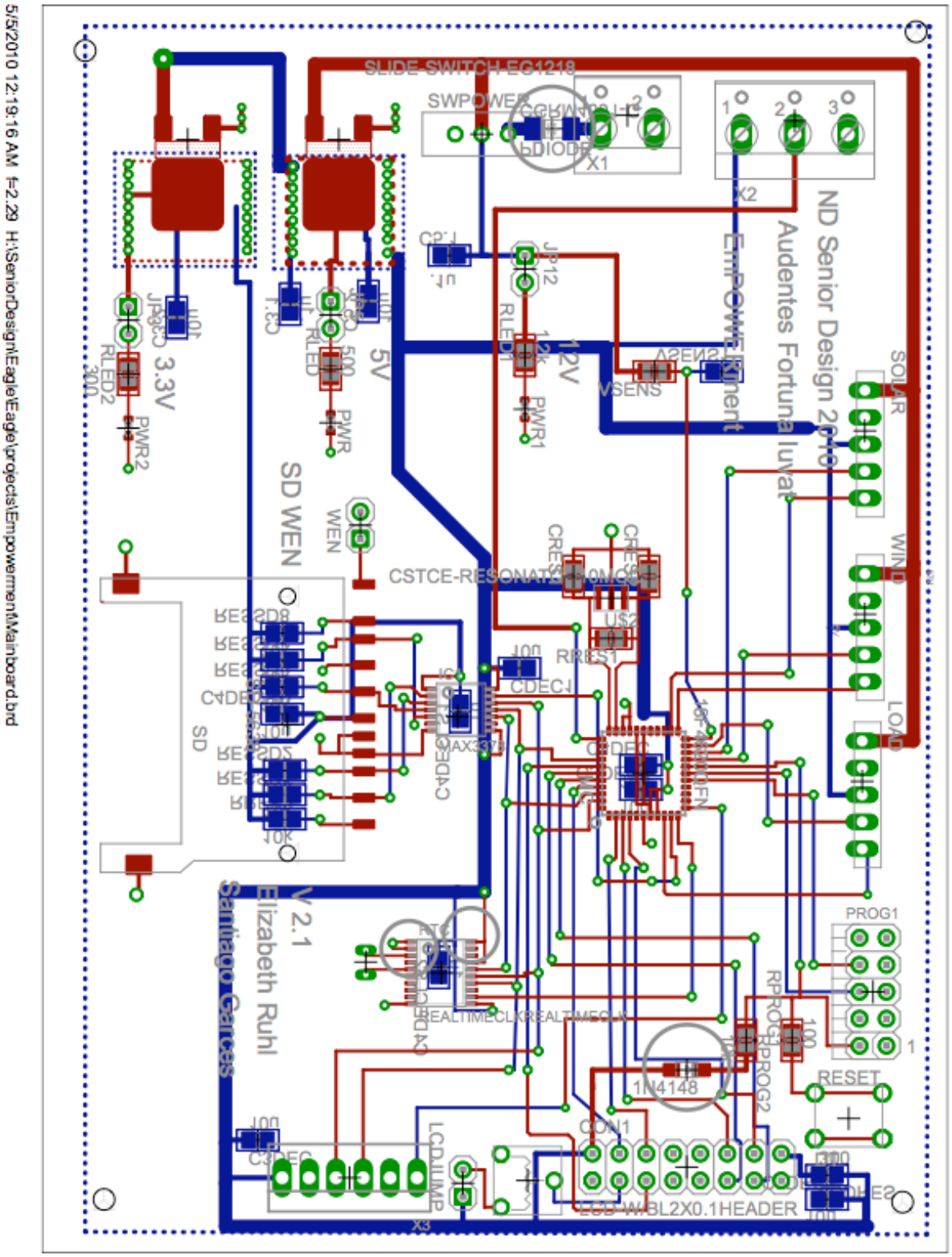
APPENDIX A: SCHEMATICS AND BOARD LAYOUTS

Note: Full Eagle Files and Libraries included on project website.

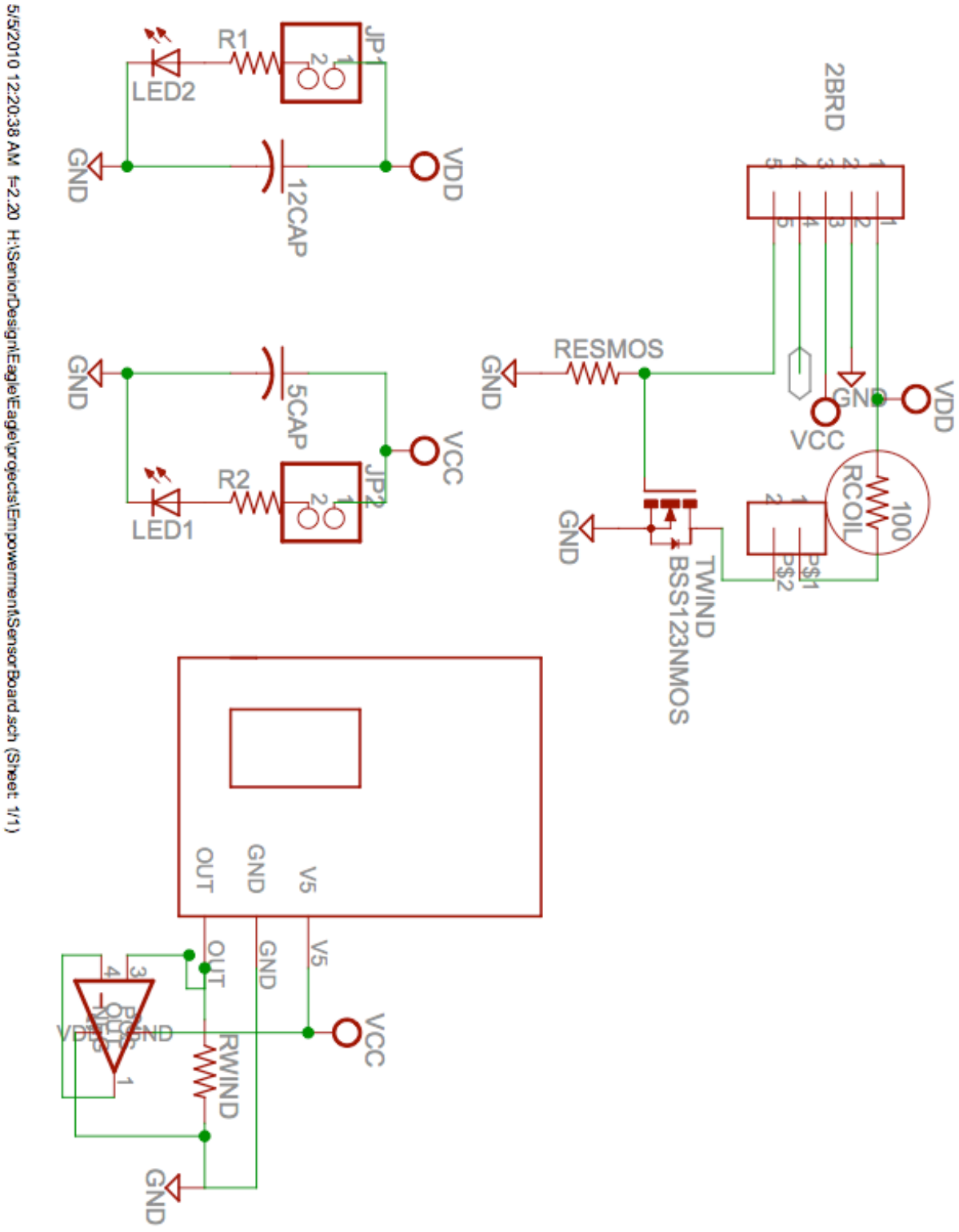
A1. Main Board Schematic:



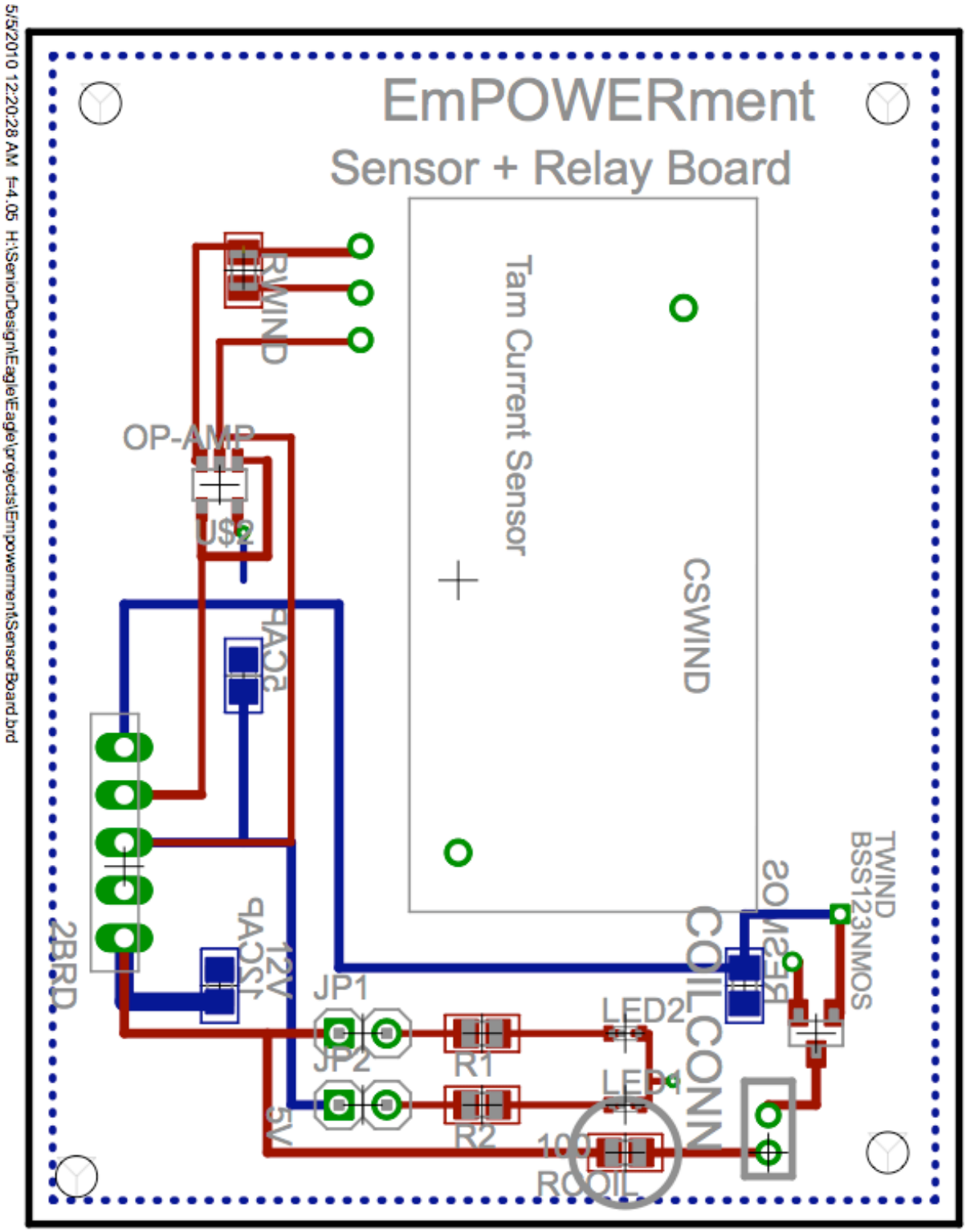
A2. Main Board Layout:



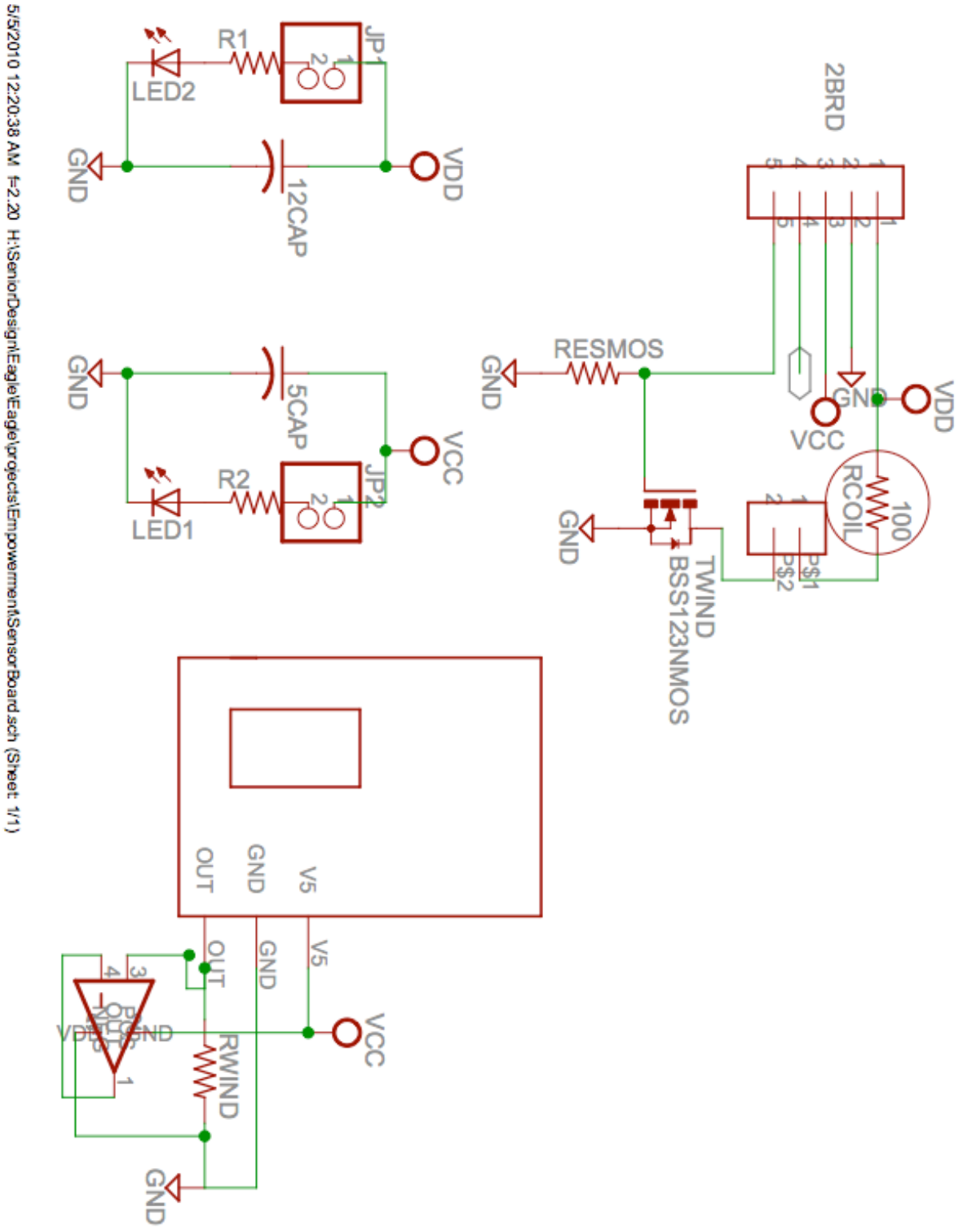
A3. Sensor Board Schematic:



A4. Sensor Board Layout:

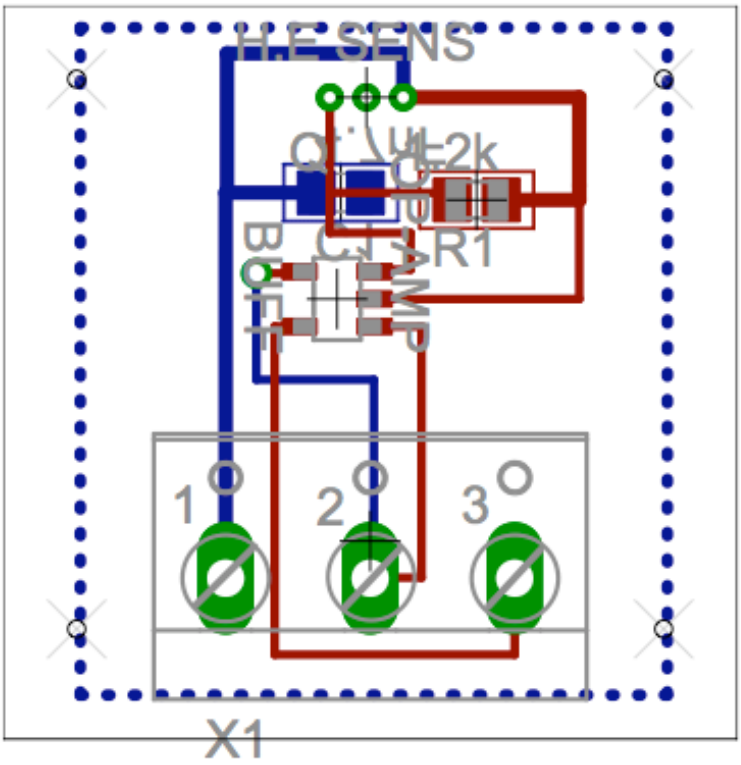


A5. Hall Effect Board Schematic:



A6. Hall Effect Sensor Board Layout:

5/5/2010 12:15:34 AM f=5.00 H:\SeniorDesign\Eagle\Eagle\projects\Empowerment\HallEffect.brd



APPENDIX B: SOFTWARE

Note: All Software is also available on the project website.

B1: A2D.h

```
#ifndef _A2D_H_
#define _A2D_H_

#include <system.h>
#include <memory.h>

unsigned short adre@ADRESL;

 unsigned short a2dRead(void);
 short a2dReadBattery (void);
 short a2dReadCSolar  (void);
 short a2dReadCLoad (void);
 short a2dReadCWind (void);
 void OscInit (void);
 void a2dInit (void);

#endif
```

B2: A2D.c

```
#include "A2D.h"
#include "spiLCD.h"


void OscInit (void)
{

      osccon  = 0b10011110;               //125kHz clock
      osctune = 0;                              //disable PLL
}


void a2dInit (void)
{
      adcon0.ADON = 1;
      adcon1.5 = 0;                 // Ref voltage is ground
      adcon1.4 = 0;                 // Ref voltage is Vdd
      adcon1.3 = 1;                 // A[0 .. 3] A2D conversion
      adcon1.2 = 0;
      adcon1.1 = 1;
      adcon1.0 = 1;
      adcon2.7 = 0;                 //Left justified
      adcon2.5 = 1;                 // A2D conversion time 20 Tad
      adcon2.4 = 1;
      adcon2.3 = 1;
      adcon2.2 = 1;                 // A2D Conversion Clock Fosc/16
      adcon2.1 = 0;
      adcon2.0 = 1;

      trisa.0  = 1;
      trisa.1  = 1;
      trisa.2  = 1;
      trisa.3  = 1;
```

```
	}

	 short a2dReadBattery (void)
{
		short voltage = 0;
		short voltagedec =0;


	//unsigned short high = 0x00ff;
	adcon0.5 = 0; // AN3 (A3) pin channel selected
	adcon0.4 = 0;
	adcon0.3 = 1;
	adcon0.2 = 1;

	    adre = 0;
		adcon0.1=1;

		while (adcon0.1);


		voltage = a2dRead();
		voltagedec = voltage;
		voltage = (voltage / 61); //only reads out as an integer

		spiLCD_printf("Bat/Batt: ");
		spiLCD_pos(2);

		spiLCD_int(voltage);
		spiLCD_printf(".");
		voltagedec = ((voltagedec % 61)*100)/61 ;
		spiLCD_int(voltagedec);
		spiLCD_printf("V ");

	return voltage;
}

	short a2dReadCSolar (void)
{

		char i;
	short current = 0;
	unsigned short currentdec;
	unsigned short sample = 0;
	//unsigned short high = 0x00ff;
	adcon0.5 = 0; // AN1 (A1) pin channel selected
	adcon0.4 = 0;
	adcon0.3 = 0;
	adcon0.2 = 1;


		//Sample 20 times
		for(i=0;i<19;i++)
		{
			adcon0.1=1; // set AD On bit
			while (adcon0.1); //While AD is active do nothing
			sample += a2dRead();
```

```
            }

            //Average samples
            sample = sample / 20;


            spiLCD_printf("Solar Corr/Curr: ");
            spiLCD_pos(2);
            current = sample - 488;
            current = (current)/3;
            spiLCD_int(current);

            spiLCD_printf(".");
            currentdec = ((sample%3)*100)/3;
            spiLCD_int(currentdec);
            spiLCD_printf("A");



      return current;
}

short a2dReadCWind (void)
{
      char i;
      short current = 0;
      unsigned short currentdec;
      unsigned short sample = 0;
      //unsigned short high = 0x00ff;
      adcon0.5 = 0; // AN0 (A0) pin channel selected
      adcon0.4 = 0;
      adcon0.3 = 0;
      adcon0.2 = 0;


            //Sample 20 times
            for(i=0;i<19;i++)
            {
                  adcon0.1=1; // set AD On bit
                  while (adcon0.1); //While AD is active do nothing
                  sample += a2dRead();

            }

            //Average samples
            sample = sample / 20;


            spiLCD_printf("Cor. Eolica/Wind:");
            spiLCD_pos(2);
            current = sample - 485;
            current = (current)/3;
            spiLCD_int(current);

            spiLCD_printf(".");
            currentdec = ((sample%3)*100)/3;
            spiLCD_int(currentdec);
            spiLCD_printf("A");
```

```
	return current;
}
short a2dReadCLoad (void)
{


	char i;
	short current = 0;
	unsigned short currentdec;
	unsigned short sample = 0;
	//unsigned short high = 0x00ff;
	adcon0.5 = 0; // AN2 (A2) pin channel selected
	adcon0.4 = 0;
	adcon0.3 = 1;
	adcon0.2 = 0;


		//Sample 20 times
		for(i=0;i<19;i++)
		{
			adcon0.1=1; // set AD On bit
			while (adcon0.1); //While AD is active do nothing
			sample += a2dRead();

		}

		//Average samples
		sample = sample / 20;


		spiLCD_printf("Cor. Carga/Load:");
		spiLCD_pos(2);
		current = sample - 486;
		current = (current)/3;
		spiLCD_int(current);
		//spiLCD_printf(" ");

		spiLCD_printf(".");
		currentdec = ((sample%3)*100)/3;
		spiLCD_int(currentdec);
		spiLCD_printf("A");



	return current;
}
unsigned short a2dRead(void)
{
	unsigned short out = 0;
	unsigned short tmp = 0xffff;

	tmp &= adresh;
	out = ((tmp << 8)| (adresl & 0x00ff));
	out = ((out >> 6) & 0x03ff);
	return out;
```

```
}
```

B3: Relay.h

```
#ifndef _RELAY_H_
#define _RELAY_H_

#include <system.h>
#include <memory.h>

void RelayInit (void);
void RelayWind_on(short);
void RelayWind_off(void);
void RelaySolar_on(unsigned char Sunset, unsigned char Sunrise, struct
CurrentTime *tp);
void RelaySolar_off(void);
void RelayLoad_on(void);
void RelayLoad_off(void);


#endif
```

B4: Relay.c

```
#include "Relay.h"
#include "spiLCD.h"



void RelayInit (void)
{
      trisa.4 = 0; //wind relay
      trisd.6 = 0; //solar relay
      trisb.0 = 0; //load relay

      RelayWind_off();
      RelaySolar_off();
      RelayLoad_off();
}
void RelayWind_on(short pmr)
{
      if (pmr > 20)
       {
            lata.4 = 1;
       }
       else
       {
            lata.4 = 0;
            spiLCD_clear();
            spiLCD_printf("Viento");
            spiLCD_pos(2);
            spiLCD_printf("Insuficiente");
            delay_s(1);
            spiLCD_clear();
            spiLCD_printf("Insufficient");
            spiLCD_pos(2);
            spiLCD_printf("Wind");
```

```
            delay_s(1);
            spiLCD_clear();

      }

}
void RelayWind_off(void)
{
      lata.4 = 0;
}
void RelaySolar_on(unsigned char Sunset, unsigned char Sunrise, struct
CurrentTime *tp)
{
      if (CurrentTime->hr >= Sunrise && CurrentTime->hr < Sunset)
            {
                  latd.6 = 1;
                  spiLCD_clear();
                  spiLCD_printf("Dia/Day");
                  spiLCD_pos(2);
                  spiLCD_printf("Solar ON");
                  delay_s(1);
            }
      else
      {
                  latd.6 = 0;
                  spiLCD_clear();
                  spiLCD_printf("Night/Noche");
                  spiLCD_pos(2);
                  spiLCD_printf("Solar OFF");
                  delay_s(1);
      }

}
void RelaySolar_off(void)
{
      latd.6 = 0;
}
void RelayLoad_on(void)
{
      latb.0 = 1;
}
void RelayLoad_off(void)
{
      latb.0 = 0;
}
```

B5: RotSens.h

```
#ifndef _ROTSENS_H_
#define _ROTSENS_H_
#include <system.h>
#include <memory.h>

unsigned short tmr0@TMR0L;

void RotSensInit(void);
#endif
```

B6: RotSens.c

```
#include "RotSens.h"



void RotSensInit(void)
{
	//Set the timer to provide an interrupt every second
	/* t0con.7 ON turns on Timer0
	t0con.6 OFF sets Timer0 as 16-bit timer
	t0con.5 OFF to use internal clock0
	t0con.4 ON to transit from low-to-high
	t0con.3 OFF prescaler is assigned
	t0con.2-0 set to 1:64
	*/
	t0con.7 = 1;
	t0con.6 = 0;
	t0con.5 = 0;
	t0con.4 = 1;
	t0con.3 = 0;
	t0con.2 = 1;
	t0con.1 = 0;
	t0con.0 = 1;

	// Set C0 to be an input
	trisc.0 = 1;
	/* t1con
		7 16-bit register enabled    0
		6 enables the internal osc   0
		5-4 prescale value 1:1        00
		3 Timer 1 osc enabled          0
		2 External clock synchronize 0
		1 External clock from pin c0 1
		0 Timer 1 on                          1
		*/
	t1con.7 = 0;
	t1con.6 = 0;
	t1con.5 = 0;
	t1con.4 = 0;
	t1con.3 = 0;
	t1con.2 = 0;
	t1con.1 = 1;
	t1con.0 = 1;

	//Enable interrupts for the microcontroller
	//Enable  Global Interrupt Enable
	intcon.7 = 0b1;
	//Enable Timer0 overflow interrupt
	intcon.5 = 0b1;
	//Preset overflow to 0
	intcon.2 = 0b0;
	//Peripheral interrupt enabled
	intcon.6 = 0b1;
	//Timer 1 interrupt disabled
	pie1.0   = 0b0;
```

```
      //preset tmr0 to 0

      tmr0h = 0xFE;
      tmr0l = 0x18;


      //LCD_printf("data begotten");
      tmr1l = 0b00000000;
      tmr1h = 0b00000000;
}
```

B7: RTClib.h

```
#ifndef _RTCLIB_H_
#define _RTCLIB_H_
#include<system.h>


struct time {
      unsigned char sec10;          // 10s place of seconds
      unsigned char sec1;           // 1s place of seconds
      unsigned char sec;            // Decimal form of seconds

      unsigned char min10;          // 10s place of minutes
      unsigned char min1;           // 1s place of minutes
      unsigned char min;            // Decimal form of minutes

      unsigned char hr10;           // 10s place of hours

      unsigned char hr1;            // 1s place of hours
      unsigned char hr;       // Decimal form of hours

      unsigned char day;            // Day of the week (Sun=1)

      unsigned char date10;   // 10s place of date
      unsigned char date1;          // 1s place of the date
      unsigned char date;           // Decimal form of hours

      unsigned char mon10;          // 10s place of the month
      unsigned char mon1;           // 1s place of the month
      unsigned char mon;            // Decimal form of month

      unsigned char yr10;           // 10s place of the year
      unsigned char yr1;            // 1s place of the year
      unsigned char yr;       // Decimal form of year
      };


unsigned char writeSPIRTC(unsigned char send);
void RTC_init(void);
char RTC_reg(char add, char input);
```

```
void RTC_set(struct time *tp);
void RTC_get(struct time *tp);
unsigned char cSunrise(unsigned char month);
unsigned char cSunset(unsigned char month);


#endif
```

B8: RTClib.c

```
#include <system.h>
#include "RTClib.h"

// Team EmPOWERment recognizes the collaboration from team SmartWindows
// with the developement of this code


#include <system.h>
#include "RTClib.h"




// Global Volatile Bits
volatile bit rtc_en@LATB.2;               // Chip Enable



void RTC_init(void){

      // Reset
      sspcon1 = 0b00000000;

      sspstat = 0b00000000;

      // SSPCON1
            //bit7:   0:    write collision, clear in software
            //bit6:   0:    receiver overflow, clear in software, avoid by
always reading buffer
            //bit5:   1:    mssp1 enable bit
            //bit4:   0:    CKP - idle state is 0 or 1
            //bit3-0: 0010: Clock speed - Fos/64
      sspcon1 = 0b00100010;
            // Sets data in, data out, and clock ports
            // BUT: must clear trisc.5 For data out
            //    must clear trisc.3 For clock

      // I/O Ports
            /* Enable:D7 --> Output 0
               SCK:   C3 --> Output 0
               MISO:  C4 --> Input  1
               MOSI:  C5 --> Output 0     */
      trisc &= 11010111b;
      trisb.2 = 0;

      // Set Default Output Values
      rtc_en = 0;       // Set chip select high
```

```
      // Set up the initial parameters
            // Control Register
            // Bit 7:   Enable Oscillator (Low True)  0
            // Bit 6:   Write Protect                              1
            // Bit 5-3: Reserved                                   000
            // Bit 2:   Int Con (Use both Int Pins?)  1
            // Bit 1:   Alarm Enable 1                             0
            // Bit 0:   Alarm Enable 0                             0
      char ans;
      ans = RTC_reg(0x8F,0b01000100);
      delay_ms(50);

      }

unsigned char writeSPIRTC(unsigned char send)
{
      //rtc_en = 1;
      sspbuf=send;
      while(!sspstat.BF);

      //rtc_en = 0;
      return sspbuf;
}

char RTC_reg(char add, char input){
      char output = 0;
      rtc_en = 1;                         // Set the chip enable low
      output = writeSPIRTC(add);    // Send an spi byte with address
      output = writeSPIRTC(input);  // Send an spi byte with the data/
      rtc_en = 0;                         // Set the chip enable low
      rtc_en = 0;
      return output;
      }


void RTC_set(struct time* tp) {
      char i;                 // Loop variable
      char ans;         // Temporary register placeholder
      char time[7];     // The time information to be sent by SPI

      time[0] = ((tp->sec10 <<4) & 0b01110000) | (tp->sec1  & 0b00001111);
      // See datasheet
      time[1] = ((tp->min10 <<4) & 0b01110000) | (tp->min1  & 0b00001111);
      time[2] = ((tp->hr10  <<4) & 0b00110000) | (tp->hr1   & 0b00001111);
      time[3] = tp->day & 0b00001111;
      time[4] = ((tp->date10<<4) & 0b00110000) | (tp->date1 & 0b00001111);
      time[5] = ((tp->mon10 <<4) & 0b00110000) | (tp->mon1  & 0b00001111);
      time[6] = ((tp->yr10  <<4) & 0b11110000) | (tp->yr1   & 0b00001111);

      ans = RTC_reg(0x8F,0b00000100);     // Disable write protect

      rtc_en = 1;                               // Send time bytes over SPI
(Burst Mode)
      ans = writeSPIRTC(0x80);                  // First address to write to
      for (i=0;i<7;i++) {
            ans = writeSPIRTC(time[i]);   // Write the 7 bytes (address inc.
automatically)
            }
```

```
      rtc_en = 0;                                  // End burst mode

      ans = RTC_reg(0x8F,0b01000100);     // Enable write protect
      return;
      }



void RTC_get(struct time* tp) {
      char tmp;         // Temporary storage variable
      struct time t;    // Structure to hold the output

      tmp = RTC_reg(0x00,0);                           // Read the seconds
register
      tp->sec10 = (tmp>>4) & 0b00000111;        // Decode the 10s place
      tp->sec1  = tmp & 0b00001111;             // Decode the 1s place
      tp->sec   = 10*tp->sec10 + tp->sec1;      // The total seconds

      tmp = RTC_reg(0x01,0);                           // Read the minutes
register
      tp->min10 = (tmp>>4) & 0b00000111;        // Decode the 10s place
      tp->min1  = tmp & 0b00001111;             // Decode the 1s place
      tp->min   = 10*tp->min10 + tp->min1;      // The total minutes

      tmp = RTC_reg(0x02,0);                           // Read the hours
register
      tp->hr10  = (tmp>>4) & 0b00000011;        // Decode the 10s place
      tp->hr1   = tmp & 0b00001111;             // Decode the 1s place
      tp->hr    = 10*tp->hr10 + tp->hr1;        // The total hour

      tmp = RTC_reg(0x03,0);                           // Read the days
register
      tp->day   = tmp & 0b00001111;             // Decode the 1s place

      tmp = RTC_reg(0x04,0);                           // Read the date
register
      tp->date10 = (tmp>>4) & 0b00000011;       // Decode the 10s place
      tp->date1  = tmp & 0b00001111;                   // Decode the 1s place
      tp->date   = 10*tp->date10 + tp->date1;   // The total date

      tmp = RTC_reg(0x05,0);                           // Read the month
register
      tp->mon10  = (tmp>>4) & 0b00000011;       // Decode the 10s place
      tp->mon1   = tmp & 0b00001111;                   // Decode the 1s place

      tp->mon    = 10*tp->mon10 + tp->mon1;     // The total month

      tmp = RTC_reg(0x06,0);                           // Read the year
register
      tp->yr10  = (tmp>>4) & 0b00001111;        // Decode the 10s place
      tp->yr1   = tmp & 0b00001111;             // Decode the 1s place
      tp->yr    = 10*tp->yr10 + tp->yr1;        // The total year
      return;
      }

unsigned char cSunrise(unsigned char month)
{
      unsigned char Sunrise;
```

```
                switch (month)
            {
                case 1:
                     Sunrise = 8;
                     return Sunrise;
                case 2:
                     Sunrise = 8;
                     return Sunrise;
                case 3:
                     Sunrise = 7;
                     return Sunrise;
                case 4:
                     Sunrise = 7;
                     return Sunrise;
                case 5:
                     Sunrise = 6;
                     return Sunrise;
                case 6:
                     Sunrise = 6;
                     return Sunrise;
                case 7:
                     Sunrise = 6;
                     return Sunrise;
                case 8:
                     Sunrise = 6;
                     return Sunrise;
                case 9:
                     Sunrise = 7;
                     return Sunrise;
                case 10:
                     Sunrise = 8;
                     return Sunrise;
                case 11:
                     Sunrise = 7;
                     return Sunrise;
                case 12:
                     Sunrise = 8;
                     return Sunrise;

            }
}


unsigned char cSunset(unsigned char month)
{
unsigned char Sunset;


                switch (month)
            {
                case 1:
                     Sunset = 18;
                     return Sunset;
                case 2:
                     Sunset = 18;
                     return Sunset;
                case 3:
```

```
                        Sunset = 19;
                        return Sunset;
                  case 4:
                        Sunset = 20;
                        return Sunset;
                  case 5:
                        Sunset = 20;
                        return Sunset;
                  case 6:
                        Sunset = 21;
                        return Sunset;
                  case 7:
                        Sunset = 21;
                        return Sunset;
                  case 8:
                        Sunset = 21;
                        return Sunset;
                  case 9:
                        Sunset = 20;
                        return Sunset;
                  case 10:
                        Sunset = 19;
                        return Sunset;
                  case 11:
                        Sunset = 17;
                        return Sunset;
                  case 12:
                        Sunset = 17;
                        return Sunset;

            }
}
```

B9: spiLCD.h

```
#ifndef _SPILCD_H_
#define _SPILCD_H_

#include <system.h>
#include <memory.h>
#include "RTClib.h"

volatile bit LCDen@LATB.3; // SPI SS LCD


void spiLCDInit(void); // initializes the SPI LCD MSSP registers trisc, latc
etc.
void spiLCD_clear(void); //clears spi LCD
void spiLCD_pos(unsigned short); // spi LCD carriage return
void spiLCD_printf( const char* text ); //sends ascii string to display
void spiLCD_int(short dat);
void spiLCD_int(char data);
void spiLCD_dec(char data);
void spiLCD_dec(unsigned short dat);
void spiLCD_dec(short dat);
void spiLCD_hex(char data);
void spiLCD_hex(unsigned short        data);
```

```
void spiLCD_hex(short data);
void spiLCD_bin(unsigned short data);
void spiLCD_bin(char data);
void spiLCD_time(struct time *tp);
void spiLCD_shiftL(void); // shift 1 unit to the left
void spiLCD_shiftR(void); //shift  1 unit to the right
void spiLCD_exitL(void); // message exits left
void spiLCD_exitR(void); // message exits right


unsigned char writeSPILCD(unsigned char);

#endif
```

B10: spiLCD.c

```
#include "spiLCD.h"



unsigned char writeSPILCD(unsigned char send)
{
      LCDen = 0;
      sspbuf=send;
      while(!sspstat.BF);

      LCDen = 1;
      return sspbuf;
}

void spiLCDInit(void)
{
      sspcon1.SSPEN=0;
      sspstat = 0b00000000;         //SMP(7)=0, CKE(6)=0 (clock edge idle to
active)
      sspcon1 = 0b00010010;         //CKP(4)=1 clock polarity (idle high)
                                          //SSPM3:SSPM0(3:0)=010 spi
clock FOSC/64 (<400kHz)
      sspcon1.SSPEN = 1;                  //SSPEN(5)=1 enable SPI



      trisb.3 = 0;
      //latb.3 = 1;
      trisc.5 = 0;
      trisc.3 = 0;
      //trisc = 0b00000000; //needs to be changed from C0 to the LCD SS
      //latc = 1;

      LCDen = 1 ;
      delay_ms(50);
}
void spiLCD_clear(void)
{
      writeSPILCD(0xFE); //clear flag for NewHaven Displays
      writeSPILCD(0X51);
      delay_ms(1);
```

```
}

void spiLCD_printf(const char* text )
{
      char i = 0;
      while( *text != 0 )
      {
      writeSPILCD( *text++ );
      //delay_ms(1);
      }
      return;
}
void spiLCD_pos(unsigned short pos)
{
      if (pos == 1)
      {
            writeSPILCD(0xFE); //clear flag for NewHaven Displays
            writeSPILCD(0X45);
            writeSPILCD(0X00);
            //delay_ms(5);
      }
      else
      {
            writeSPILCD(0xFE); //clear flag for NewHaven Displays
            writeSPILCD(0X45);
            writeSPILCD(0X40);
      }
}
void spiLCD_dec(short dat)
{
      unsigned short val;   // ascii results
      unsigned short temp;
      unsigned short div;
      unsigned short data;
      char i;
      char digit;
      data = dat;  // make it unsigned
      div = 10000;
      for(i=0; i <= 4; ++i)   // get all 5 digits
      {
            val = data/div;       // get most signif. digit
            writeSPILCD(val + '0');    // print digit
            data -= val * div;   // what we've printed
            div=div/10;         // adjust divisor
      }
      return;
}

void spiLCD_dec(unsigned short dat)
{
      unsigned short val;   // ascii results
      unsigned short temp;
      unsigned short div;
      unsigned short data;
      char i;
      char digit;
      data = dat;  // make it unsigned
      div = 10000;
```

```
	for(i=0; i <= 4; ++i)   // get all 5 digits
	{
		val = data/div;       // get most signif. digit
		writeSPILCD(val + '0');    // print digit
		data -= val * div;   // what we've printed
		div=div/10;         // adjust divisor
	}
	return;
}
/*********************************
* Display byte as decimal number *
*********************************/
void spiLCD_dec(char data)
{
	writeSPILCD(((data /100) & 255) + 0x30);
	data = data % 100;
	writeSPILCD( ((data / 10) & 255) + 0x30 );
	writeSPILCD( ((data % 10) & 255) + 0x30 );
	return;
}
/*
* display char as a signed int
* */

void spiLCD_int(char data)
{
	char val;   // ascii results
	char temp;
	char div;
	char i;
	bool dozero;
	dozero = false;
	div = 100;
	if(data == 0)  // always print 0
	{
		writeSPILCD('0');
		return;
	}
	/*
		* adjust for sign
		* */
	if(data & 10000000b)
	{
		writeSPILCD('-');
		data = ~data + 1;
	}
	for(i=0; i <= 2; ++i)   // get all 3 digits
	{
		val = data/div;       // get most signif. digit
		if(val != 0 || dozero)
		{
			writeSPILCD(val + '0');    // print digit
			dozero = true;
		}
		temp = val * div;   // subtract off
		data = data - temp;   // what we've printed
		div=div/10;         // adjust divisor
	}
```

```
}

/*
* display unsigned short as a signed int
* */

void spiLCD_int(short dat)
{
      short val;   // ascii results
      short temp;
      short div;
      char i;
      unsigned short data;
      bool dozero;
      dozero = false;
      data = dat;
      if(dat == 0)  // always print 0
      {
            writeSPILCD('0');
            return;
      }
      div = 10000;
      /*
            * adjust for sign
            * */
      if(dat < 0)
      {
            writeSPILCD('-');
            data = ~data + 1;
      }
      for(i=0; i <= 4; ++i)   // get all 3 digits
      {
            val = data/div;       // get most signif. digit
            if(val != 0 || dozero)
            {
                  writeSPILCD(val + '0');    // print digit
                  dozero = true;
            }
            //          temp = val * div;   // subtract off
            data -= val*div;   // what we've printed
            div=div/10;         // adjust divisor
      }
}
void spiLCD_hex(char data)
{
      char n;
      n = ((data >> 4) & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      n = (data & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      return;
}
/*******************************
* Display unsigned short in HEX - format *
*******************************/
void spiLCD_hex(unsigned short        data)
```

```
{
      char n;
      n = ((data >> 12) & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      n = ((data >> 8) & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      n = ((data >> 4) & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      n = (data & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      return;
}
/*******************************
* Display  short in HEX - format *
*******************************/
void spiLCD_hex(short data)
{
      char n;
      n = ((data >> 12) & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      n = ((data >> 8) & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      n = ((data >> 4) & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      n = (data & 0x0F) + 0x30;
      if (n > 0x39) n = n+7;
      writeSPILCD(n);
      return;
}
      void spiLCD_bin(char data)
{
      char n;
      char temp;
      temp =0x80;
      for( n=1; n<=8; ++n)
      {
            if(temp & data)
            writeSPILCD(0x31);
            else
            writeSPILCD(0x30);
            temp = temp >> 1;
      }
      return;
}
/*******************************
* Display unsigned short in binary - format *
*******************************/
void spiLCD_bin(unsigned short data)
{
      char n;
      unsigned short temp;
```

```
	temp =0x8000;
	for( n=1; n<=16; ++n)
	{
		if(temp & data)
		writeSPILCD(0x31);
		else
		writeSPILCD(0x30);
		temp = temp >> 1;
	}
}
void spiLCD_time(struct time *tp)
{
	spiLCDInit();
	spiLCD_clear();
	spiLCD_int(tp->hr10);
	spiLCD_int(tp->hr1);
	spiLCD_printf(":");
	spiLCD_int(tp->min10);
	spiLCD_int(tp->min1);
	spiLCD_printf(":");
	spiLCD_int(tp->sec10);
	spiLCD_int(tp->sec1);
	spiLCD_pos(2);
	spiLCD_int(tp->date);
	spiLCD_printf(".");
	spiLCD_int(tp->mon);
	spiLCD_printf(".20");
	spiLCD_int(tp->yr10);
	spiLCD_int(tp->yr1);

	return;
}
void spiLCD_shiftL(void)
{
	writeSPILCD(0xFE); //clear flag for NewHaven Displays
	writeSPILCD(0X55);
	delay_ms(1);
}
void spiLCD_shiftR(void)
{
	writeSPILCD(0xFE); //clear flag for NewHaven Displays
	writeSPILCD(0X56);
	delay_ms(1);
}

void spiLCD_exitL(void)
{
	char i = 0;
		for (i;i<15; i++)
		{
			spiLCD_shiftL();
			delay_ms(500);
		}

}
void spiLCD_exitR(void)
{
	char i = 0;
```

```
            for (i;i<15; i++)
            {
                  spiLCD_shiftR();
                  delay_ms(500);
            }
}
```

B11: main.c

```
#include "spiLCD.h"
#include "A2D.h"
#include "Relay.h"
#include "RotSens.h"
#include "RTClib.h"


#pragma     CLOCK_FREQ  125000 //125kH
#pragma DATA _CONFIG1H, _OSC_INTIO67_1H
#pragma DATA _CONFIG2H, _WDT_OFF_2H
#pragma DATA _CONFIG4L, _LVP_OFF_4L & _XINST_OFF_4L
#pragma DATA _CONFIG3H, _MCLRE_ON_3H

//////////////////////////
//
// Variables to calculate the wind turbine speed
// every second timer0 overloads and interrupts making sec++
// after 15 sec the interrupt rutine checks the count on timer1 (the
rotations)
// and multiplies it by 4, to find rpm
//////////////////////////

short rot = 0;
short sec = 0;
short rpm = 0;
//////////////////////////
//
// Variables to calculate the sunrise and sunset
//
//
//////////////////////////
unsigned char Month;
unsigned char Sunset;
unsigned char Sunrise;

///////////////////////////
//
// Sensors and Power variables
//
//
///////////////////////////

short Vbat;
short CSolar;
short CWind;
short CLoad;
short pIn;  // Power In
short pOut; //Power Out
```

```
short pTot; // Total Power




void main (void){

      ////////////////////////////////
      // Intitizalization Routine
      //
      ////////////////////////////////
      //Inits
      //
      ////////////////////////////////

      OscInit();        //Oscillator Init
      RTC_init();       //Real time Clock
      a2dInit();        //A2D Init
      RelayInit();      //Relay Init
      RotSensInit();    //Rotation Sensor Init
      spiLCDInit();     //LCD Init

      tmr0= 0xFDA8; //sets initial timer 2000 counts before int.

      //Clear display
      spiLCD_clear();
      //Set Time

      //Init. Time
       struct time initTime, *pinitTime;
       pinitTime = &initTime;

       struct time CurrentTime, *pCurrentTime;
       pCurrentTime = &CurrentTime;


      initTime.sec10 = 0x00;        // 10s place of seconds
      initTime.sec1  = 0x00;        // 1s place of seconds

      initTime.min10 = 0x00;        // 10s place of minutes
      initTime.min1  = 0x00;        // 1s place of minutes

      initTime.hr10  = 0x01;        // 10s place of hours

      initTime.hr1   = 0x03;        // 1s place of hours

      initTime.day   = 0x05;        // Day of the week (Sun=1)

      initTime.date10 = 0x02; // 10s place of date
      initTime.date1  = 0x09;       // 1s place of the date

      initTime.mon10  = 0x00;       // 10s place of the month
      initTime.mon1   = 0x04;       // 1s place of the month

      initTime.yr10   = 0x01;       // 10s place of the year
      initTime.yr1    = 0x00;       // 1s place of the year
```

```
	RTC_init();
	RTC_set(pinitTime) ;
	delay_ms(30);



	// Switch the Relays once each to indicate that the system works

	spiLCDInit();

	//Wind
	spiLCD_printf("Eolica/Wind R");
	RelayWind_on(rpm);
	delay_s(1);
	spiLCD_pos(2);
	spiLCD_printf("^_^");
	RelayWind_off();
	delay_s(1);
	//Solar
	spiLCD_clear();
	spiLCD_printf("Solar R");
	RelaySolar_on(Sunset ,Sunrise, pCurrentTime);
	delay_s(1);
	spiLCD_pos(2);
	spiLCD_printf("^_^");
	RelaySolar_off();
	delay_s(1);
	//Load
	spiLCD_clear();
	spiLCD_printf("Carga/Load R");
	RelayLoad_on();
	delay_s(1);
	spiLCD_pos(2);
	spiLCD_printf("^_^");
	RelayLoad_off();



	while (1)
{



	spiLCD_clear();
	Vbat   = a2dReadBattery();
	delay_s(2);
	spiLCD_clear();
	CWind  = a2dReadCWind();
	delay_s(2);
	spiLCD_clear();
	CSolar = a2dReadCSolar();
	delay_s(2);
	spiLCD_clear();
	CLoad  = a2dReadCLoad();
	delay_s(2);
	spiLCD_clear();
```

```
      //Geting Time
      RTC_init();
      RTC_get(pCurrentTime);
      //Calculate Sunrise and Sunset
      Month   = 10*CurrentTime.mon10 + CurrentTime.mon1;    // The total
month
      Sunrise = cSunrise(Month);
      Sunset  = cSunset(Month);


      spiLCDInit();

      //Display Sunrise and Sunset


                  spiLCD_printf("Aman./S.Rise: ");
                  spiLCD_int(Sunrise);
                  spiLCD_pos(2);
                  spiLCD_printf("Sunset: ");
                  spiLCD_int(Sunset);
                  delay_s(1);
                  spiLCD_clear();


            if  ((Vbat >= 14) && ((CWind + CSolar) >= CLoad)      ) //
Battery Full
            {
                  //Inputs are off, Output on
                  RelayWind_off();
                  RelaySolar_off(); //Solar OFF
                  RelayLoad_on();

                  spiLCD_printf("Bateria");
                  spiLCD_pos(2);
                  spiLCD_printf("Battery");
                  delay_s(1);
                  spiLCD_clear();
                  spiLCD_printf("Full");
                  delay_s(1);
                  spiLCD_clear();
                  spiLCD_printf("Entradas/Inputs");
                  spiLCD_pos(2);
                  spiLCD_printf("OFF");
                  delay_s(1);

            }
            else if  ((Vbat >= 14) && ((CWind + CSolar) < CLoad) ) //Battery
Full, O>I
            {
                  //Inputs are on, Output on
                  RelayWind_on(rpm);
                  RelaySolar_on(Sunset, Sunrise, pCurrentTime); // Solar OFF
                  RelayLoad_on();

                  spiLCD_printf("Bateria");
                  spiLCD_pos(2);
                  spiLCD_printf("Battery");
```

```
                delay_s(1);
                spiLCD_clear();
                spiLCD_printf("Full");
                delay_s(1);
                spiLCD_clear();
                spiLCD_printf("Entradas/Inputs");
                spiLCD_pos(2);
                spiLCD_printf("OFF");

          }
          else if (((Vbat < 14) && (Vbat > 10))&&(CurrentTime.hr >=Sunrise
&& CurrentTime.hr < Sunset ))// Battery OK, IO irrelevant, Daytime
          {
                RelayWind_on(rpm);
                RelaySolar_on(Sunset,Sunrise,pCurrentTime);
                RelayLoad_on();

                spiLCD_printf("Bateria");
                spiLCD_pos(2);
                spiLCD_printf("Battery");
                delay_s(1);
                spiLCD_clear();
                spiLCD_printf("OK");
                delay_s(1);
                spiLCD_clear();
                spiLCD_printf("Salida/Outp.");
                spiLCD_pos(2);
                spiLCD_printf("ON");
                delay_s(1);


          }
          else if ( (Vbat <= 10) && ((CWind + CSolar) <= CLoad)) // Battery
Dis. O Off,
          {
                RelayWind_on(rpm);
                RelaySolar_on(Sunset,Sunrise,pCurrentTime);
                RelayLoad_off();

                spiLCD_printf("Bateria");
                spiLCD_pos(2);
                spiLCD_printf("Battery");
                delay_s(1);
                spiLCD_clear();
                spiLCD_printf("Desc/Disch");
                delay_s(1);
                spiLCD_clear();
                spiLCD_printf("Salida/Outp.");
                spiLCD_pos(2);
                spiLCD_printf("OFF");
                delay_s(1);

          }
          else if ( (Vbat <= 10) && ((CWind + CSolar) > CLoad))// Battery
Disc. O. Off,
          {
                RelayWind_on(rpm);
                RelaySolar_on(Sunset,Sunrise,pCurrentTime);
```

```
            RelayLoad_on();

            spiLCD_printf("Bateria");
            spiLCD_pos(2);
            spiLCD_printf("Battery");
            delay_s(1);
            spiLCD_clear();
            spiLCD_printf("Desc/Disch");
            delay_s(1);
            spiLCD_clear();
            spiLCD_printf("Salida/Outp.");
            spiLCD_pos(2);
            spiLCD_printf("OFF");
            delay_s(1);
            spiLCD_clear();
      }
      else
      {
      RelayWind_off();
      RelaySolar_off();
      RelayLoad_off();

      spiLCD_printf("ERROR!");
      delay_s(1);


      }

//Calculate Power

pIn  = ((CWind+CSolar) * Vbat);
pOut = (CLoad * Vbat);
pTot= pIn - pOut;

spiLCD_clear();
spiLCD_printf("Poder/Power Gen.");
spiLCD_pos(2);
spiLCD_int(pIn);
spiLCD_printf(" W");
delay_s(1);
spiLCD_exitL();

spiLCD_clear();
spiLCD_printf("Poder/Power Cons.");
spiLCD_pos(2);
spiLCD_int(pOut);
spiLCD_printf(" W");
delay_s(1);
spiLCD_exitR();

spiLCD_clear();
spiLCD_printf("Poder/Power Net.");
spiLCD_pos(2);
spiLCD_int(pTot);
spiLCD_printf(" W");
delay_s(1);
spiLCD_exitL();
```

```
      spiLCD_clear();
      spiLCD_printf("Vel. Turbina");
      spiLCD_pos(2);
      spiLCD_printf("Rot.Spd. ");
      spiLCD_int(rpm);
      spiLCD_printf("RPM");
      delay_s(1);
      spiLCD_exitL();


      //Get Current Time
      RTC_init();
      RTC_get(pCurrentTime);

      //Display Time
      spiLCDInit();
      spiLCD_time(pCurrentTime);
      delay_s(1);
      spiLCD_exitL();



      }

}

void interrupt(void) {
tmr0= 0xFE18; // Pre fill the counter 2000 counts short
intcon.2 = 0b0; //Clear intterupt flag
if (sec == 15){
                  rot = ((tmr1h * 256) & (0xFF00))+ tmr1l; //rot = timer1
                  rpm = rot * 4;
                  tmr1l = 0;
                  tmr1h = 0;
                  sec = 0;
                  }


sec ++;

}
```

APPENDIX C: BILL OF MATERIALS

Note: All technical specifications along with the bill of materials complete with web access information can be found on the project website.

Part Desc.	Manuf. Part #	Digikey #
MAIN BOARD		
Microcontroller	PIC18F4620	PIC18F4620-I/ML-ND
Ceramic Resonator, 20 MHz	CSTCE20M0V53Z-R0	490-4717-1-ND
5V-3.3V Voltage Reg.	LD1117#33	497-1236-2-ND
12V-5V Reg.	LD1117#50	497-1237-1-ND
5V-3.3V Level Translator	MAX3378EUD+	
SD Card Holder	Kyocera-5638	478-4058-1-ND
SD Card 512MB		
Real Time Clock	MAXIM DS1305-E+	DS1305E+-ND
Crystal Oscillator for RTClk	ECS-.327-8-14X	X1125-ND
SPI LCD Display	NHD-0216K3Z-FS(RGB)-FBW	
6x1 Header (SPI LCD)		WM2715-ND
6x1 Freehanging,		WM2616-ND
Sliding Switch	EG1218	EG1903-ND
Reset Button	ESE-20C343	P12346S-ND
2x5 Pinheader (programmer)		
Diode for Programmer	1N4148	1N4148WXTPMSCT-ND
3-pin screw terminal (HEB)		A98167-ND
2-pin screw terminal (Battert)		A98166-ND
RELAY BOARD (3)		
Relays, Chassis Mount	CB1F-D-M-12V	255-2729-ND
Power MOSFETS	NDS355AN	NDS355ANTR-ND
Current Sensors	L01Z-100SO5	MT7174-ND
Op-Amp	TC1034ECT	TC1034ECTTRCT-ND
Male Header, 5pin	22-05-3051	WM4303-ND
Female Freehang, 5pin	22-01-2055	WM2615-ND
2x1 Male Header		
Power Switches		
HALL EFFECT BOARD		
3-pin Screw Terminal (board and back)		A98077-ND
Hall Effect Sensor	TLE4905L	TLE4905LE6433INCT-ND
Magnet		469-1002-ND
Learning Center Stock Parts		
Indicator LEDs		
Resistors	100 Ohm	
	300 Ohm	
	1 kOhm	
	1.2 kOhm	
	5.1 kOhm	
	10 kOhm	

Supplier	Cost per unit	Quantity	Total Cost	Manufacturer
Microchip Sample	$8.12	1	$8.12	Microchip
Learning Center	$0.61	1	$0.61	Murata Electronics
Digikey	$0.22	1	$0.83	ST
Digikey	$0.77	1	$0.77	ST
Maxim Sample	$0.00	1	$0.00	MAXIM
Learning Center	$4.79	1	$4.79	Kyocera
Donated	$0.00	1	$0.00	SanDisk
Maxim Sample	$0.00	1	$0.00	Maxim
Digikey	$0.63	1	$0.63	ECS
New Haven	$21.90	1	$21.90	New Haven
Digikey	$2.16	2	$4.32	Molex
Digikey	$0.69	2	$1.38	Molex
Learning Center	$0.73	1	$0.73	E-Switch
Learning Center	$1.82	1	$1.82	Panasonic
LC	$0.00	1	$0.00	
Learning Center	$0.38	1	$0.38	Micro Commercial Co
Digikey	$0.85	1	$0.85	Tyco
Digikey	$0.55	1	$0.55	Tyco
Digikey	$4.80	3	$14.40	Panasonic
Digikey	$0.13	3	$0.40	Fairchild
Digikey	$17.75	3	$53.25	Tamura
Digikey	$0.74	3	$2.22	Microchip
Digikey	$0.95	6	$5.70	Molex
Digikey	$0.53	6	$3.18	Molex
LC	$0.00	3	$0.00	
LC	$0.00	4	$0.00	
Digikey	$0.60	2	$1.20	Tyco Electronics
Digikey	$1.16	1	$1.16	Infineon
Digikey	$0.60	8	$4.80	Radial Manet, Inc.
	$0.00	9	$0.00	
	$0.00	1	$0.00	
	$0.00	15	$0.00	
	$0.00	1	$0.00	
	$0.00	4	$0.00	
	$0.00	6	$0.00	
	$0.00	4	$0.00	

Part Desc.	Manuf. Part #	Digikey #
	20 kOhm	
	50 kOhm	
Capacitors	15 pF	
	4.7 nF	
	.1 uF	
	1 uF	
	10 uF	
Spade Lugs, Various Connectors		
Housing		
Polycase Box (10x6x3)		DC-96F
Polycase Box (2x2x1.5)		BF-020215
Box Cover		C-0202
Aluminum Splices		
Lumber, Hardware (Batt. stand)		
Power Generation		
Air-X Blades		
Hub (wood, bolts)		
8" Single Bore Pulley		
V-belt		
AC Delco Alternator		
1/2" Dowel		
2-Bolt Flange bearing, .5" bore	Dayton	
Lumber, Hardware		
Koekraf Panels, 20W		
Lumber, Hardware (Panel Stands)		
Hinges, 3"		
Hinges, 2"		
Inverter	Cobra CPI 480	
10 Gauge Wire (20 Ft)		
14 Gauge Wire (10 Ft)		

Supplier	Cost per unit	Quantity	Total Cost	Manufacturer
	$0.00	6	$0.00	
	$0.00	1	$0.00	
	$0.00	2	$0.00	
	$0.00	2	$0.00	
	$0.00	6	$0.00	
	$0.00	6	$0.00	
	$0.00	4	$0.00	
Learning Center	$0.00	30	$0.00	
Polycase	$12.04	1	$12.04	
Polycase	$1.34	1	$1.34	
Polycase	$0.00	1	$0.00	
Lowe's	$5.19	4	$20.76	
Learning Center	$0.00		$0.00	
AME Dept.	$0.00	1	$0.00	Southwest Wind Power
LC	$0.00	1	$0.00	
Grainger Industrial Supply	$15.00	1	$15.00	
Auto Store	$3.00	1	$3.00	
Auto Store	$69.00	1	$69.00	
Lowe's	$1.44	1	$1.44	
Grainger Industrial Supply	$16.15	2	$32.30	
LC	$0.00		$0.00	
ND CSE Dept.	$0.00	2	$0.00	
LC	$0.00		$0.00	
Lowe's	$2.38	4	$11.78	
Lowe's	$1.13	2	$2.26	
donrowe.com	$34.00	1	$34.00	
Lowe's	$2.22	1	$2.22	
EE Lab	$0.00	1	$0.00	